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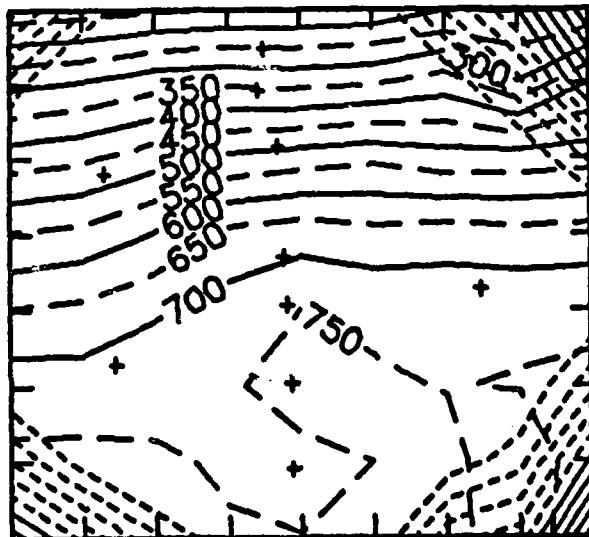
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# THE SYNOP PILOT

## EXPERIMENT:

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Inverted Echo Sounder Data Report  
for  
November 1986 to March 1987



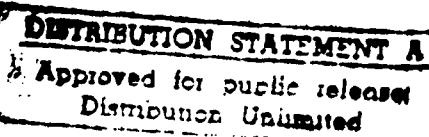
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GSO Technical Report Number 88-1

November 1988

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GRADUATE SCHOOL OF OCEANOGRAPHY  
UNIVERSITY OF RHODE ISLAND  
NARRAGANSETT, RHODE ISLAND

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This research program has been sponsored by the Office of Naval Research under contract  
N00014-86-C-0394.

## Abstract

The SYNOP Pilot Experiment was conducted off Cape Hatteras, from late November 1986 to early March 1987, to measure the path characteristics (position, angle, curvature), the time-varying current structure and transport of the Gulf Stream. Part of the purpose of this Experiment was to test new instrumentation techniques and moored array designs for a subsequent main SYNOP Experiment. Data collected as part of the Pilot Experiment included Inverted Echo Sounders (IESs), Current Meter moorings (CMs) and Acoustic Transport Meters (ATMs). This report documents the IES data and ATM data collected during the deployment period. Time series plots of the travel time and low-pass filtered thermocline depth measurements are presented for eleven instruments. Bottom pressure and temperature, measured at three of the sites, are also plotted. Basic statistics are given for all the data records shown. Maps of the thermocline depth field in a 160 Km by 140 Km region are presented at daily intervals.

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# 1 Experiment Description and Data processing

## 1.1 Introduction

This report documents data collected using Inverted Echo Sounders (IESs) in the Gulf Stream off Cape Hatteras from November 1986 to March 1987. The measurements were made under the support of an ONR project entitled "SYNOP Pilot Experiment." Other data collected as part of this Pilot Experiment included (a) two Current Meter moorings (CMs) with five levels of each mooring, at depths of 400, 700, 1000 and 2000 m and 50 m above the bottom (Co-P.I., J. Bane, University of North Carolina), (b) tests of two acoustic doppler current profilers at the top of these moorings (W. Johns, University of Miami), (c) tests of two Acoustic Transport Meters (ATMs) (D.R. Watts, University of Rhode Island), (d) Pegasus surveys of velocity and temperature sections (K. Leaman, University of Miami), (e) tests of a new electromagnetic towed transport meter (T. Sanford, University of Washington, APL), and (f) Pop-up-profiler (A. Bradley, WHOI). The ATM data are included in this report. The other data will be documented separately.

The principal objectives of the IES and ATM portion of this SYNOP Pilot Experiment are as follows:

1. developing improved techniques for monitoring inflow conditions of the Gulf Stream as it leaves Cape Hatteras, and
2. mapping the thermocline topography by objective analysis in the region surrounding the current meter and Pegasus surveys.

The specific inflow conditions that we wish to monitor are

- path characteristics (position, angle, curvature)
- detailed cross-stream structure of the thermocline
- baroclinic and barotropic transport
- stream function and vorticity.

To contribute to our planned dynamical and statistical studies later in the SYNoptic Ocean Prediction program (SYNOP), these inlet parameters are seen as a generalization

and improvement of earlier work for the purpose of specifying "inlet conditions" for numerical prediction of the synoptic variability of the Gulf Stream farther downstream.

To address these objectives, an array of IESs, CMs and ATMs were deployed within the Gulf Stream near 35°N 74°W. In this region, there is a minimum in the lateral meander motion, as determined from several years of satellite observations of the Gulf Stream's surface temperature front.

The nine IESs and two ATMs (and two CMs) were deployed on a cruise aboard the R/V ENDEAVOR (EN152) from 20 November to 3 December 1986, and recovered on the R/V ENDEAVOR (EN156) from 26 February to 6 March 1987. During this three-month-period, the instruments were located on three sections in an rectangular grid 160 Km downstream by 140 Km cross-stream. The IES sites, designated by the solid circles in Figure 1, are spaced 35 Km cross-stream and 50 Km alongstream. Acoustic transport meters and current meter moorings are located at the sites shown by the two solid triangles. These are situated halfway between adjacent IESs, thereby giving a 35 Km spacing between them as well. Additionally, bottom pressure gauges and bottom temperature sensors are included at three IES sites located along line B (indicated by the solid box). All IES and ATM sites are listed in Table 1.

## 1.2 Site Naming Conventions

The three cross-stream sections are designated from west to east by the letters A through C. The IES sites along line A and line C are numbered from 1 through 2, and line B consecutively from 1 through 7, with site 1 located at the northwestern end of the section. In this report, each instrument site is referred to by both the section letter and site number, prefaced by either IES, if it is a standard instrument, or PIES, if it is a combined IES and bottom pressure gauge. For example, IES87B5 is the fifth site from the northern end of line B. Additionally, the preface ATM indicates an acoustic transport meter site.

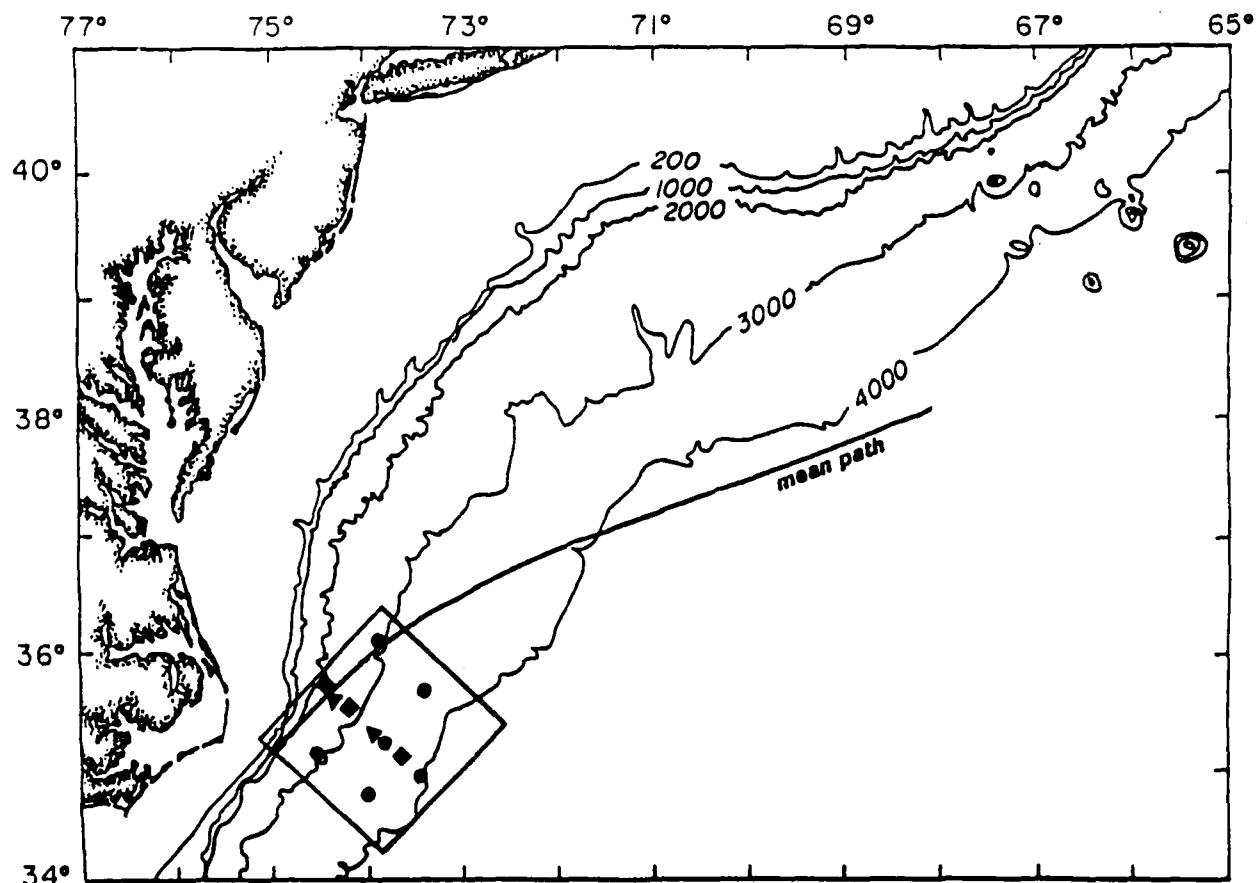


Figure 1: The SYNOP Pilot Experiment field observations area.

All IES (circles) and ATM (triangles) sites were occupied from November 1986 through February 1987. PIESs with bottom pressure gauges and temperature sensors are located at the solid rectangular boxes. The box is the 160 Km by 140 Km region, which is shown in Figure 12. The solid line through the area shows the historical mean path of the Gulf Stream.

Table 1: Site Location and Data Returns

SITE	LATITUDE(N)	LONGITUDE(W)	DEPLOYMENT
			PERIOD (DATES)
IES87A1	35°16.12	74°32.94	Nov 28 - Mar 2
IES87A2	34°58.08	74°07.89	Nov 27 - Mar 2
PIES87B1	35°45.64	74°27.93	Nov 25 - Feb 28
ATM87B2	35°40.67	74°23.52	Nov 30 - Feb 28
PIES87B3	35°37.07	7 °13.92	Nov 26 - Mar 1
ATM87B4	35°26.50	73°59.47	Nov 24 - Feb 28
IES87B5	35°22.06	73°53.06	Nov 26 - Feb 28
PIES87B6	35°14.54	73°42.92	Nov 27 - Feb 28
IES87B7	35°06.05	73°31.94	Nov 27 - Mar 1
IES87C1	36°02.80	73°52.90	Nov 23 - Mar 3
IES87C2	35°43.98	73°29.98	Nov 27 - Mar 3

### 1.3 Inverted Echo Sounder Description

A detailed description of the IES is presented in Chaplin and Watt's (1984) and will not be repeated here. Briefly, however, the IES is an instrument which is moored one meter above the ocean floor and which monitors the depth of the main thermocline acoustically. A sample burst of acoustic pulses is transmitted every half hour and round trip travel times to the surface and back are recorded on a digital cassette tape within the instrument. For the standard IES, a sample burst typically consists of twenty 10 KHz pings. Additionally, bottom pressure and temperature can be measured and recorded. For instruments with these optional sensors, the travel time burst consists of 24 pings, whereas the pressure and temperature are average measurements over the whole sampling interval.

#### 1.4 Data Processing

Most of the earlier processing was done on a PRIME 750 computer, except for the initial dumping of the data from the cassette tapes onto a 9-track magnetic tape. This was done on the Hewlett Packard 2000 series computer maintained by the URI Marine Technicians. At the last major step, objective mapping, the processing was done on our Micro Vax II computer system. The basic processing steps, which include transcription, editing, and conversion into scientific units, are illustrated by the flowchart in Figure 2. The data processing is accomplished by a series of routines specifically developed for the IES. Since these programs are documented elsewhere (Tracey and Watts, 1988), the steps are only outlined below.

**RAW DATA CASSETTES** : Recorded within the instruments. Contain the counts associated with travel time, pressure, and temperature measurements as a series of integer words of varying lengths.

**CARP** : Transfers the data from cassettes to 9-track magnetic tape for subsequent processing.

**BUNS** : Converts the series of integer words of varying lengths into standard length 32-bit integer words.

**PUNS** : Produces integer listings and histograms of the travel time sample bursts. Provides an initial look at data quality and travel time distributions. Used to determine the first (after launch) and last (before recovery) 'on bottom' samples.

**MEMOD** : Establishes the time base. Determines either the median or modal value (at the user's option) of the travel time burst as the representative measurement. Converts all travel time, pressure and temperature counts into specific units of seconds, decibars, and degrees Celsius, respectively.

**FILL** : Checks for proper incrementing of the time base. Missing data points are filled by inserting interpolated values.

**DETIDE** : From user-supplied tidal constituents specific to each site, determines the tidal contribution to the travel times and removes it from the measured values.

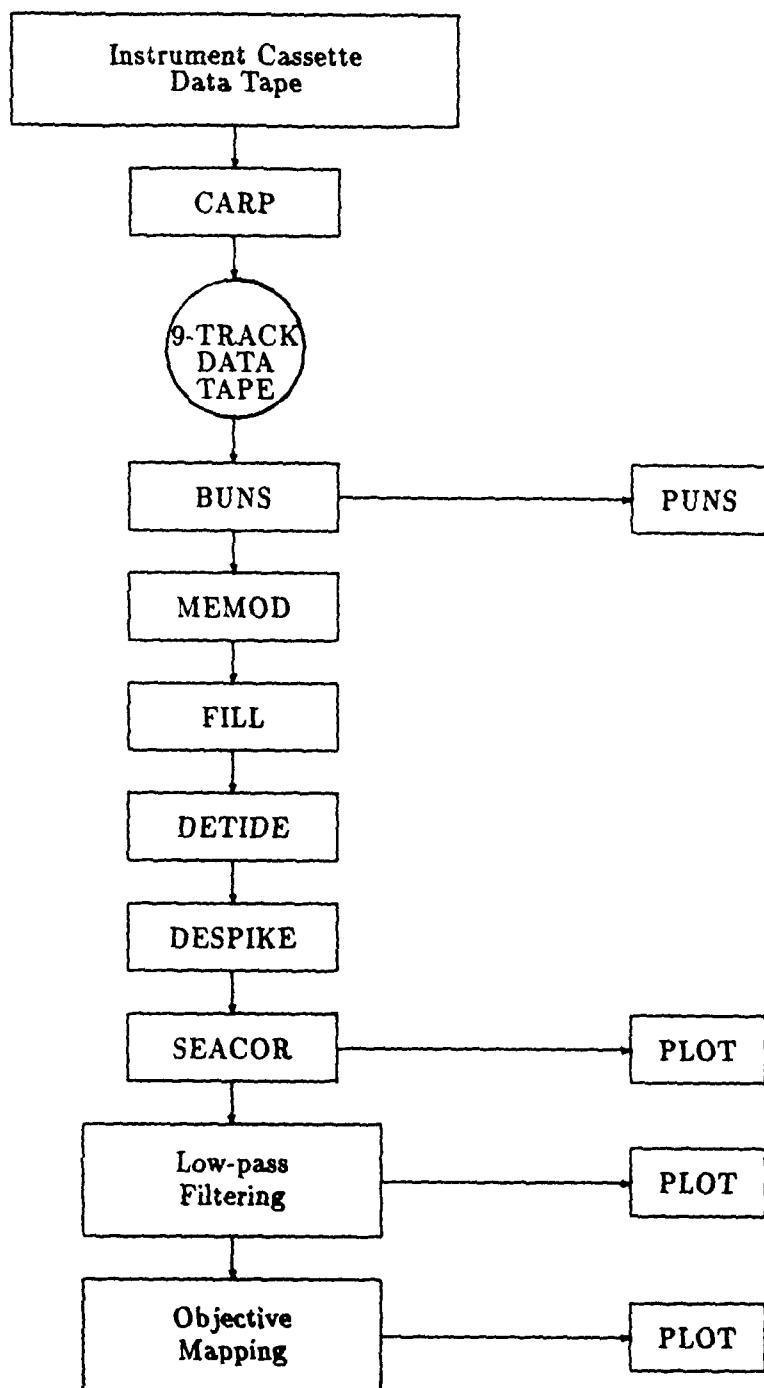


Figure 2: IES Data Processing Flowchart.

**DESPIKE** : Identifies and replaces travel time spikes with interpolated values.

**SEACOR** : Removes the effects of seasonal warming and cooling of the surface layers from the travel times. Plots of the half-hourly pressure, temperature and travel time are generated.

**LOW PASS FILTERING** : Convolves the travel times, pressures, and temperatures with a 40 hours low-pass Lanczos filter. The smoothed series are subsampled at six hour intervals and plotted.

**OBJECTIVE MAPPING** : Produces daily maps of the depth of the 12°C isotherm as documented in Watts, Tracey and Friedlander, 1988.

The **FESTSA** time series analysis package (Brooks, 1976), modified for the PRIME 750, was used to remove the higher frequency (tidal and inertial) motions from those with periods of several days or longer, which are the main focus of this project. The symmetric filter, with a Lanczos taper, was designed with the quarter power point at 0.025 cph and the tidal cycle attenuated by 60 dB. The half-hourly travel time, pressure, and temperature data were low-pass filtered and the smoothed output series (40 HRLP) had sampling intervals of six hours.

#### 1.4.1 Travel Time Calibration

Variations in the travel times have been shown to be proportional to variations in the thermocline depth (Watts and Rossby, 1977; Watts and Wimbush, 1981). Calibration XBTs were taken at each IES site in order to convert the travel times ( $\tau$ ) into thermocline depths ( $\xi$ ) according to the relation:  $\xi = M\tau + B$ , where  $M$  is a scale factor and the intercept  $B$  depends on the depth of the instrument. Regressions of  $\tau$  versus  $\xi$ , performed for several instruments, show that the constant ( $M$ ) value,  $M = -19.0$  m/msec for the 12°C isotherm, is appropriate for all these Gulf Stream sites. The values of  $B$  used for each instrument are listed in the tables in Section 2. For practical purposes the main thermocline depth can be represented by the depth of an individual isotherm. For this work, we have chosen the 12°C isotherm since it is situated near the highest temperature gradients of the main thermocline and correlates well with  $\tau$  (Rossby, 1969; Watts and Johns, 1982). The low-pass

filtered travel time records were scaled to the thermocline depths ( $Z_{12}$ ) and these records are shown in Section 4. Since  $\tau$  is resolved to 0.1 msec, the 40 HRLP  $Z_{12}$  scaled values are therefore resolved to  $\pm 2$  m. However, the accuracy of the offset parameter B is estimated to be  $\pm 25$  m for most instruments, judged from the agreement between the several calibration XBTs taken at each site. Relative to this, the 40 HRLP  $Z_{12}$  values are resolved to  $\pm 2$  m.

#### 1.4.2 Thermocline Depth Mapping

Objective maps of the thermocline ( $Z_{12}$ ) field in the array region have been produced at daily intervals from these records. The boxed region in Figure 1, oriented  $045^\circ\text{T}$ , is the region which has been mapped. The objective mapping techniques were developed by E. Carter (1983) and special adaptations for their application to the Gulf Stream frontal zone are discussed in Watts and Tracey (1985). Two results presented in this latter work are of particular importance to the objective mapping performed here: 1) If the mean field is removed, the perturbations have essentially isotropic correlation fields. 2) The space-time correlation functions used for the objective analysis are shown.

The objective analysis is performed on the "perturbation fields", which are obtained by removing the mean field from the input dataset and normalizing by the standard deviation. To represent the mean field,  $\overline{Z_{12}}(x, y)$ , where x is alongstream ( $045^\circ\text{T}$ ) and y is cross-stream ( $315^\circ\text{T}$ ), a third order polynomial was fitted to the mean values observed during the November 1986 to March 1987 deployment period. The function form of the polynomial was:

$$\overline{Z_{12}}(x, y) = B_o + B_1 x + B_2 y + B_{11} x^2 + B_{12} x y + B_{22} y^2 + B_{111} x^3 + B_{112} x^2 y + B_{122} x y^2 + B_{222} y^3$$

where  $(x, y)$  is the position in kilometers from the origin at  $35^\circ\text{N}, 74^\circ\text{W}$ ,  $B_o$  is  $0.76533772E + 03$ ,  $B_1$  is  $0.6320926E + 00$ ,  $B_2$  is  $-0.4103623E + 01$ ,  $B_{11}$  is  $-0.8553885E - 02$ ,  $B_{12}$  is  $0.1851212E - 01$ ,  $B_{22}$  is  $-0.5083383E - 01$ ,  $B_{111}$  is  $0.5500527E - 04$ ,  $B_{112}$  is  $-0.9935370E - 04$ ,  $B_{122}$  is  $-0.6128939E - 04$ , and  $B_{222}$  is  $0.3236166E - 03$ . The standard deviation field,  $\sigma(x, y)$ , was defined as a function of the mean field depth, from a Gaussian form

representative of all IES records:

$$\sigma(x, y) = A + B \exp \left( - \left[ \frac{\overline{Z_{12}}(x, y) - Z_o}{C} \right]^2 \right)$$

where A is 50 m, B is (200 m - A), C is 200 m,  $Z_o$  is 470 m, and  $\overline{Z_{12}}(x, y)$  is the mean thermocline depth at that (x,y) location. Figure 10 shows both the mean and standard deviation fields in plain view. The objectively estimated error fields are shown in Figure 11.

For each output grid point, the objective mapping technique selects , from all the input data within a specified maximum time lag (T) and radial (R), the number of the points (N) which have the highest correlations. The output fields in Figure 12 result from specifying N = 6, T =  $\pm 1$  days, R = 120 Km, and using the idealized correlation function (Watts and Tracey, 1985) with an assumed noise level E = 0.05.

The output of the objective mapping is the perturbation field on a full grid of points, with 20 Km grid spacing, within a 160 Km by 140 Km mapping region. The thermocline depth maps (shown in Figure 12) are obtained by renormalizing the perturbation field by the standard deviation and restoring the mean. Tracey et al. (1987) report an accuracy of 47 m for these output  $Z_{12}$  fields.

#### 1.4.3 Temperature

Temperatures (Figure 6) were measured using thermistors (Yellow Springs International Corp., model 44032 ) controlled by Sea Data Corp. (model DC-37B) electronics cards installed in the IESs, in order to correct the pressure values for the temperature sensitivity of the transducer. The thermistor is inside the instrument, on the pressure transducer, rather than in the water. However, once the temperature probe has reached equilibrium with the surrounding waters, it also provides accurate measurements of the bottom temperature fluctuations (effectively low-pass filtered with a 40 hour e-folding equilibrium time). The first 24 half-hourly points were dropped prior to low-pass filtering, since the temperatures took 12 hours to reach equilibrium within  $0.001^{\circ}\text{C}$ . The accuracy of the temperature measurements is about  $0.1^{\circ}\text{C}$ , and the resolution is  $0.0002^{\circ}\text{C}$ .

#### 1.4.4 Bottom Pressure

Digiquartz pressure sensor (models 46K-032 and 76KB-032) manufactured by Paro-scientific, Inc. were used to measure bottom pressure. All pressure measurements were corrected for the temperature sensitivity of the transducer, using calibration coefficients purchased from the manufacturer. The half-hourly measured bottom pressures (Figure 4) are dominated by the tides, however for some of the instruments, the pressures also drift, 0(0.4 dbar), monotonically with time. Processing of the pressure measurements includes removing the long-term drift and tides as follows.

Tidal response analysis (Munk and Cartwright, 1977) was used to determine the tidal constituents for each instrument. The calculated tides were then removed from the pressure records. The amplitudes, H (dbar), and phases,  $G^\circ$  (Greenwich epoch), of the constituents are given in the tables in Section 2.

In order to estimate and remove the long-term drift from the measurements, we made least-squares fits of exponential and exponential-linear curves to our data (Watts and Kontoianis, 1986). The mathematical formulas we used here were:

$$\text{Drift} = P_1[1 - \exp(P_2 t)] + P_3$$

for the exponential curve and

$$\text{Drift} = P_1[1 - \exp(P_2 t)] + P_3 + P_4 t$$

for the exponential-linear curve. Here  $t$  is the time in hours, relative to the approximate deployment time, which is 13 hours before the first data point used.  $P_1$ ,  $P_2$ ,  $P_3$ , and  $P_4$  are free parameters determined for each instrument by the non-linear regression subroutine P3R of BMDP-79, a package of computer programs developed at the Health Science Computing Facility, UCLA (Dixon and Brown, 1979). These coefficients are listed in Section 2 for PIERS87B1 and PIERS87B3.

The half-hourly pressures are resolved to 0.001 dbar and the mean pressure is accurate to within 1.5 dbar. We estimate that the residual (drift and tide removed) bottom pressure

records, shown in Figure 5, have an accuracy (relative to their mean pressure) of better than 0.05 dbar (Watts and Kontoyiannis, 1986). The residual bottom pressure records were low-pass filtered (Figure 8) as mentioned above.

#### 1.4.5 Time Base

The date and time were assigned to each sampling period. The tables in Section 2, report the hours, minutes, and seconds associated with the first and last sampling period as a six-digit number. All times are given as Greenwich Mean Time (GMT). For processing convenience, the times were converted into yearhours. Table 2 lists the yearhour which corresponds to 0000 GMT of each day for non-leap years. (For leap years, the yearhours can be determined by adding 24 to each day after February 28.) There are a total of 8760 hours in a standard year and 8784 hours in a leap year. The yearhours given in this report are referenced to January 1, 1987 at 0000 GMT, with measurements occurring between January and March 1987 assigned positive yearhours. Negative values correspond to the sampling period from November through December 1986.

### 1.5 Acoustic Ocean-Transport Meter Description

The acoustic transport meter, described in Chaplin and Watts (1986), is a new instrument which is presently under development. We conducted the first extensive test deployments of the ATM prototypes during the SYNOP Pilot Experiment.

The ATM consists of three separate components, a master transceiver and two slave transponders. These components are moored in a triangular pattern, at nominal spacings of 3 Km. The master is a microprocessor-controlled IES which has had its sampling scheme reprogrammed. The typical configuration has 32 measurements taken per hour at approximately 56 s intervals to allow ample time for all signals to be received and/or dissipated.

In addition to measuring transport, the master and slave components can perform other operations. The master functions as a traditional IES, measuring the thermocline depth at its deployment site. The two slaves can serve as navigation transponders for the Pegasus velocity profiler. During a Pegasus drop, the ATM is sent a coded signal and sampling is reduced to one measurement per hour so as not to interfere with the Pegasus acoustics.

Table 2: Yearhour Calendar for Non-Leap Years. Only the yearhour corresponding to 0000 GMT is listed for each day.

JAN		FEB		MAR		APR		MAY		JUNE	
!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR
! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!
1 1 11 0 1 1 321 744	1 1 11 601 1416	1 1 11 911 2160	1 1 11 1211 2880	1 1 11 1521 3624							
1 2 21 24 1 2 331 768	1 1 2 611 1440	1 1 2 921 2184	1 1 2 1221 2904	1 1 2 1531 3648							
1 3 31 48 1 3 341 792	1 1 3 621 1464	1 1 3 931 2208	1 1 3 1231 2928	1 1 3 1541 3672							
1 4 41 72 1 4 351 816	1 1 4 631 1488	1 1 4 941 2232	1 1 4 1241 2952	1 1 4 1551 3696							
1 5 51 96 1 5 361 840	1 1 5 641 1512	1 1 5 951 2256	1 1 5 1251 2976	1 1 5 1561 3720							
1 6 61 123 1 6 371 864	1 1 6 651 1536	1 1 6 961 2280	1 1 6 1261 3000	1 1 6 1571 3744							
1 7 71 144 1 7 381 888	1 1 7 661 1560	1 1 7 971 2304	1 1 7 1271 3024	1 1 7 1581 3768							
1 8 81 168 1 8 391 912	1 1 8 671 1584	1 1 8 981 2328	1 1 8 1281 3048	1 1 8 1591 3792							
1 9 91 192 1 9 401 935	1 1 9 681 1608	1 1 9 991 2352	1 1 9 1291 3072	1 1 9 1601 3816							
1 10 101 216 1 10 411 960	1 1 10 691 1632	1 1 10 1001 2376	1 1 10 1301 3096	1 1 10 1611 3840							
1 11 111 240 1 11 421 984	1 1 11 701 1655	1 1 11 1011 2400	1 1 11 1311 3120	1 1 11 1621 3864							
1 12 121 264 1 12 431 1008	1 1 12 711 1680	1 1 12 1021 2424	1 1 12 1321 3144	1 1 12 1631 3888							
1 13 131 288 1 13 441 1032	1 1 13 721 1704	1 1 13 1031 2448	1 1 13 1331 3168	1 1 13 1641 3912							
1 14 141 312 1 14 451 1056	1 1 14 731 1728	1 1 14 1041 2472	1 1 14 1341 3192	1 1 14 1651 3936							
1 15 151 336 1 15 461 1080	1 1 15 741 1752	1 1 15 1051 2496	1 1 15 1351 3216	1 1 15 1661 3960							
1 16 161 360 1 16 471 1104	1 1 16 751 1776	1 1 16 1061 2520	1 1 16 1361 3240	1 1 16 1671 3984							
1 17 171 384 1 17 481 1128	1 1 17 761 1800	1 1 17 1071 2544	1 1 17 1371 3264	1 1 17 1681 4008							
1 18 181 408 1 18 491 1152	1 1 18 771 1824	1 1 18 1081 2568	1 1 18 1381 3288	1 1 18 1691 4032							
1 19 191 432 1 19 501 1176	1 1 19 781 1848	1 1 19 1091 2592	1 1 19 1391 3312	1 1 19 1701 4056							
1 20 201 456 1 20 511 1200	1 1 20 791 1872	1 1 20 1101 2616	1 1 20 1401 3336	1 1 20 1711 4080							
1 21 211 480 1 21 521 1224	1 1 21 801 1896	1 1 21 1111 2640	1 1 21 1411 3360	1 1 21 1721 4104							
1 22 221 504 1 22 531 1248	1 1 22 811 1920	1 1 22 1121 2664	1 1 22 1421 3384	1 1 22 1731 4128							
1 23 231 528 1 23 541 1272	1 1 23 821 1944	1 1 23 1131 2688	1 1 23 1431 3408	1 1 23 1741 4152							
1 24 241 552 1 24 551 1296	1 1 24 831 1968	1 1 24 1141 2712	1 1 24 1441 3432	1 1 24 1751 4176							
1 25 251 576 1 25 561 1320	1 1 25 841 1992	1 1 25 1151 2736	1 1 25 1451 3456	1 1 25 1761 4200							
1 26 261 600 1 26 571 1344	1 1 26 851 2016	1 1 26 1161 2760	1 1 26 1461 3480	1 1 26 1771 4224							
1 27 271 624 1 27 581 1368	1 1 27 861 2040	1 1 27 1171 2784	1 1 27 1471 3504	1 1 27 1781 4248							
1 28 281 648 1 28 591 1392	1 1 28 871 2064	1 1 28 1181 2808	1 1 28 1481 3528	1 1 28 1791 4272							
1 29 291 672 1		1 29 881 2088	1 1 29 1191 2832	1 1 29 1491 3552	1 1 29 1801 4296						
1 30 301 696 1		1 30 891 2112	1 1 30 1201 2856	1 1 30 1501 3576	1 1 30 1811 4320						
1 31 311 720 1		1 31 901 2136		1 31 1511 3600							

JULY		AUG		SEPT		OCT		NOV		DEC	
!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR	!DATE!YEAR! HOUR
! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!	! DAY!(0000Z)!
1 1 1821 4344 1 1 1 2131 5088	1 1 1 2411 5832	1 1 1 2741 6552	1 1 1 3051 7296	1 1 1 3351 8016							
1 2 1831 4368 1 2 2 2141 5112	1 1 2 2451 5856	1 1 2 2751 6576	1 1 2 3061 7320	1 1 2 3361 8040							
1 3 1841 4392 1 3 3 2151 5136	1 1 3 2461 5880	1 1 3 2761 6600	1 1 3 3071 7344	1 1 3 3371 8064							
1 4 1851 4416 1 4 4 2161 5160	1 1 4 2471 5904	1 1 4 2771 6624	1 1 4 3081 7368	1 1 4 3381 8088							
1 5 1861 4440 1 5 5 2171 5184	1 1 5 2481 5928	1 1 5 2781 6648	1 1 5 3091 7392	1 1 5 3391 8112							
1 6 1871 4464 1 6 6 2181 5208	1 1 6 2491 5952	1 1 6 2791 6672	1 1 6 3101 7416	1 1 6 3401 8136							
1 7 1881 4488 1 7 7 2191 5232	1 1 7 2501 5976	1 1 7 2801 6696	1 1 7 3111 7440	1 1 7 3411 8160							
1 8 1891 4512 1 8 8 2201 5256	1 1 8 2511 6000	1 1 8 2811 6720	1 1 8 3121 7464	1 1 8 3421 8184							
1 9 1901 4536 1 9 9 2211 5280	1 1 9 2521 6024	1 1 9 2821 6744	1 1 9 3131 7488	1 1 9 3431 8208							
1 10 1911 4560 1 10 10 2221 5304	1 1 10 2531 6048	1 1 10 2831 6768	1 1 10 3141 7512	1 1 10 3441 8232							
1 11 1921 4584 1 11 11 2231 5328	1 1 11 2541 6072	1 1 11 2841 6792	1 1 11 3151 7536	1 1 11 3451 8256							
1 12 1931 4608 1 12 12 2241 5352	1 1 12 2551 6096	1 1 12 2851 6816	1 1 12 3161 7560	1 1 12 3461 8280							
1 13 1941 4632 1 13 13 2251 5376	1 1 13 2561 6120	1 1 13 2861 6840	1 1 13 3171 7584	1 1 13 3471 8304							
1 14 1951 4656 1 14 14 2261 5400	1 1 14 2571 6144	1 1 14 2871 6864	1 1 14 3181 7608	1 1 14 3481 8328							
1 15 1961 4680 1 15 15 2271 5424	1 1 15 2581 6168	1 1 15 2881 6888	1 1 15 3191 7632	1 1 15 3491 8352							
1 16 1971 4704 1 16 16 2281 5448	1 1 16 2591 6192	1 1 16 2891 6912	1 1 16 3201 7656	1 1 16 3501 8376							
1 17 1981 4728 1 17 17 2291 5472	1 1 17 2601 6216	1 1 17 2901 6936	1 1 17 3211 7680	1 1 17 3511 8400							
1 18 1991 4752 1 18 18 2301 5496	1 1 18 2611 6240	1 1 18 2911 6960	1 1 18 3221 7704	1 1 18 3521 8424							
1 19 2001 4776 1 19 19 2311 5520	1 1 19 2621 6264	1 1 19 2921 6984	1 1 19 3231 7728	1 1 19 3531 8448							
1 20 2011 4800 1 20 20 2321 5544	1 1 20 2631 6288	1 1 20 2931 7008	1 1 20 3241 7752	1 1 20 3541 8472							
1 21 2021 4824 1 21 21 2331 5568	1 1 21 2641 6312	1 1 21 2941 7032	1 1 21 3251 7776	1 1 21 3551 8496							
1 22 2031 4848 1 22 22 2341 5592	1 1 22 2651 6336	1 1 22 2951 7056	1 1 22 3261 7800	1 1 22 3561 8520							
1 23 2041 4872 1 23 23 2351 5616	1 1 23 2661 6360	1 1 23 2961 7080	1 1 23 3271 7824	1 1 23 3571 8544							
1 24 2051 4896 1 24 24 2361 5640	1 1 24 2671 6384	1 1 24 2971 7104	1 1 24 3281 7848	1 1 24 3581 8568							
1 25 2061 4920 1 25 25 2371 5664	1 1 25 2681 6408	1 1 25 2981 7128	1 1 25 3291 7872	1 1 25 3591 8592							
1 26 2071 4944 1 26 26 2381 5688	1 1 26 2691 6432	1 1 26 2991 7152	1 1 26 3301 7896	1 1 26 3601 8616							
1 27 2081 4968 1 27 27 2391 5712	1 1 27 2701 6456	1 1 27 3001 7176	1 1 27 3311 7920	1 1 27 3611 8640							
1 28 2091 4992 1 28 28 2401 5736	1 1 28 2711 6480	1 1 28 3011 7200	1 1 28 3321 7944	1 1 28 3621 8664							
1 29 2101 5016 1 29 29 2411 5760	1 1 29 2721 6504	1 1 29 3021 7224	1 1 29 3331 7968	1 1 29 3631 8688							
1 30 2111 5040 1 30 30 2421 5784	1 1 30 2731 6528	1 1 30 3031 7248	1 1 30 3341 7992	1 1 30 3641 8712							
1 31 2121 5064 1 31 31 2431 5808			1 31 3041 7272		1 31 3641 8736						

After the Pegasus operations have been completed, normal sampling resumes

Unfortunately during the Pilot Experiment, the ATMs did not function correctly. Two unrelated problems occurred which resulted in poor data returns. First, deploying the three ATM components at just the right spacings so that all the required acoustic signals are received without interfering with each other or with extraneous echos is a more subtle and difficult job than we had realized. Consequently, the deployment sites of the three ATM components were not optimal, and some of the acoustic signals required for the transport calculations either were not recorded or interfered with each other's detected transit time. Hence, in this report only thermocline depth measurements are reported for the ATMs.

Secondly, after operating normally for several days, both instruments automatically switched from the "normal" sampling mode into the "Pegasus" sampling mode. For one instrument, ATM87B2, even the Pegasus-mode was unusual with 8 measurements made at irregular intervals during each hour. Thus special data processing was required to obtain accurate thermocline depth values from the travel time measurements.

The data records of both ATM87B2 and ATM87B4 were split into two sections based on the sampling modes. Different processing was performed on the different sections.

Both instruments sampled normally (32 measurements per hour) during the first portions. These travel time data were grouped into hourly "bursts" and processed as in Section 1.4 for an IES through the MEMOD and DESPIKE programs. Since these initial records were only about five days long, the high frequency motions were removed using a 12-hour lowpass-filter in place of the typical 40-hour lowpass-filter. The output data were subsampled at 6-hour intervals and scaled to thermocline depths. Since these records are very short, they are not shown in Figures 3.2 and 7.2. However the data have been used to contribute to the objective maps shown in Section 5.

For the two instruments, the second portions (Pegasus-mode) of the travel time records were processed differently. For ATM87B2, with only 8 samples per hour, the data were grouped into 12-hour "bursts" prior to IES processing and removing the travel time spikes. The data for ATM87B4, with only one sample per hour, were similarly grouped and processed, except in 24-hour "bursts". For both instruments, the start time for each "burst" is stepped forward at a 6 hour interval (the bursts overlap). The processed vertical travel time data from the ATMs are shown in Figure 3.2. Lowpass-filtering was performed using a 96-hour Lanczos filter. The filtered data (Figure 7.2) have a sampling interval of 24 hours

and were scaled to thermocline depths in the same manner as for the other IESs.

## 1.6 Data Recovery

Table 1 summarizes the data returns from each of the IESs and ATMs. All nine instruments were recovered, giving a recovery rate of 100%. IES87C1 ceased functioning properly about one month after the instrument was launched. All the remaining instruments performed successfully, yielding a 91% data return for the travel time measurements. Complete records were obtained from all three bottom pressure gauges; however the data record from one of these (PIES87B6) had large jumps, indicating its sensor malfunctioned, thus the recovery rate for the bottom pressure data was only 67%. Complete records were obtained from all three temperature gauges; thus the return rate was 100% for these data.

## 2 Individual Site and Record Information Tables

The following tables provide informations about the location, dates, and basic statistics on the data records. Each table documents a single instrument site.

General site information, such as position, bottom depth, and launch and recovery times, is given first. Subsequently, details about the travel time, bottom pressure, temperature and thermocline depth records plotted in Section 3 and 4 are tabulated. For each plot, the times associated with the first and last data point are supplied. All yearhours are referenced to January 1, 1987 at 0000 GMT. Measurements made during the calendar year prior to the reference date are given as negative yearhours.

The first order statistics (minimum, maximum, mean, and standard deviation) were calculated for the half-hourly and 40 HRLP records for each variable of standard IES and PIES, and for the six-hourly and 96 HRLP records for that of two ATMs. These are also presented in the following tables.

**Table 3. Site and Record Information for  
IES87A1**

Serial Number: 043  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 20  
 Additional Sensors: None

POSITION: 35°16.12 N DEPTH: 2660 m  
 74°32.94 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 28, 1986	023900	EN152
RECOVERY:	Mar 2, 1987	190400	EN156

**TRAVEL TIME RECORDS**  
 Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	033135	-812.4736
LAST DATA POINT:	Mar 2, 1987	190133	1459.0258

Number of Points: 4544  
 Sampling Interval: 0.5 hrs

Minimum  $\tau$  = 3.52552 s                          Mean = 3.53130 s  
 Maximum  $\tau$  = 3.54078 s    Standard Deviation = 0.00263 s

**40HRLP THERMOCLINE DEPTH RECORDS**  
 Fig. 7.1

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$   
 where B = 67541.63 m  
 $\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	120000	-780.00
LAST DATA POINT:	Mar 1, 1987	120000	1428.00

Number of Points: 369  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12}$  = 313.34 m                          Mean = 447.74 m  
 Maximum  $Z_{12}$  = 522.71 m    Standard Deviation = 46.97 m

**Table 4. Site and Record Information for  
IES87A2**

Serial Number: 045  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 20  
 Additional Sensors: None

POSITION: 34°58.08 N DEPTH: 3280 m  
 74°07.89 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	230500	EN152
RECOVERY:	Mar 2, 1987	143300	EN156

**TRAVEL TIME RECORDS**

Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000135	-815.9736
LAST DATA POINT:	Mar 2, 1987	143133	1454.5258

Number of Points: 4542  
 Sampling Interval: 0.5 hrs

Minimum  $\tau$  = 4.34647 s                          Mean = 4.35049 s  
 Maximum  $\tau$  = 4.35414 s    Standard Deviation = 0.00108 s

**40HRLP THERMOCLINE DEPTH RECORDS**

Fig. 7.1

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$   
 where  $B = 83377.92$  m  
 $\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	060000	-786.00
LAST DATA POINT:	Mar 1, 1987	060000	1422.00

Number of Points: 369  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12}$  = 682.58 m                          Mean = 718.22 m  
 Maximum  $Z_{12}$  = 757.91 m    Standard Deviation = 16.05 m

**Table 5. Site and Record Information for  
PIES87B1**

Serial Number: 058  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 24  
 Additional Sensors: Pressure and Temperature  
 Pressure Sensor Serial Number: 19327

POSITION: 35°45.64 N DEPTH: 1950 m  
 74°27.93 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 25, 1986	205600	EN152
RECOVERY:	Feb 28, 1987	093836	EN156

#### TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 25, 1986	213151	-866.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4537  
 Sampling Interval: 0.5 hrs

Minimum  $\tau$  = 0.19395 s                          Mean = 0.20100 s  
 Maximum  $\tau$  = 0.20586 s    Standard Deviation = 0.00193 s

#### 40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where B = 4045.00 m

$\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	060000	-834.00
LAST DATA POINT:	Feb 27, 1987	000000	1368.00

Number of Points: 368  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12}$  = 164.37 m                          Mean = 226.57 m  
 Maximum  $Z_{12}$  = 313.92 m    Standard Deviation = 33.06 m

### PIES87B1 (continue)

#### MEASURED PRESSURE RECORDS

Fig. 4

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 25, 1986	213151	-866.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4537  
 Sampling Interval: 0.5 hrs

Minimum = 1964.16 dbar                    Mean = 1964.88 dbar  
 Maximum = 1965.79 dbar   Standard Deviation = 0.33140 dbar

#### RESIDUAL PRESSURE RECORDS

Fig. 5

$$P_{\text{residual}} = P_{\text{measured}} - \text{MEAN} - \text{DRIFT} - \text{TIDE}$$

$$\text{DRIFT} = P_1[1 - \exp(-P_2 t)] + P_3 + P_4 t$$

where t = Time of sample in hours, starting with  
 t = 13.0 hrs for the first data point

$$P_1 = 1.167470 \text{ dbar}$$

$$P_2 = -0.000321 \text{ dbar}$$

$$P_3 = 0.078548 \text{ dbar}$$

$$P_4 = 0.000231 \text{ dbar}$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	.42831	.10012	.09006	.02148	.09056	.07172	.02964	.01654
G°:	353.09	335.93	19.74	21.35	182.59	188.09	183.70	183.94

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	093151	-854.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4513  
 Sampling Interval: 0.5 hrs

Minimum = -0.1354 dbar                    Mean = 0.0005 dbar  
 Maximum = 0.1181 dbar   Standard Deviation = 0.0309 dbar

**PIES87B1 (continue)****40HRLP PRESSURE RECORDS**

Fig. 8

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	180000	-822.0000
LAST DATA POINT:	Feb 27, 1987	000000	1368.0000

Number of Points: 366  
 Sampling Interval: 6.0 hrs

Minimum = -0.1099 dbar                    Mean = 0.0003 dbar  
 Maximum = 0.0562 dbar   Standard Deviation = 0.0235 dbar

**TEMPERATURE RECORDS**

Fig. 6

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 25, 1986	213151	-866.4692
LAST DATA POINT:	Feb 28, 1987	093151	1401.5308

Number of Points: 4537  
 Sampling Interval: 0.5 hrs

Minimum = 3.490 °C                    Mean = 3.784 °C  
 Maximum = 3.991 °C   Standard Deviation = 0.103 °C

**40HRLP TEMPERATURE RECORDS**

Fig. 9

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	180000	-822.0000
LAST DATA POINT:	Feb 27, 1987	000000	1368.0000

Number of Points: 366  
 Sampling Interval: 6.0 hrs

Minimum = 3.533 °C                    Mean = 3.784 °C  
 Maximum = 3.953 °C   Standard Deviation = 0.086 °C

**Table 6. Site and Record Information for ATM87B2**

Serial Number: 064

Type of Travel Time Detector: TTD

Number of Pings per Sampling: refer to Sec. 1.5

Additional Sensors: None

POSITION:  $35^{\circ}40.67\text{ N}$  DEPTH: 2300 m  
 $74^{\circ}23.52\text{ W}$

	DATE	GMT	CRUISE
LAUNCH:	Nov 30, 1986	215700	EN152
RECOVERY:	Feb 28, 1987	065600	EN156

#### RAW TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Dec 4, 1986	141742	-657.7051
LAST DATA POINT:	Feb 28, 1987	011742	1393.2951

Number of Points: 343

Sampling Interval: 6.0 hrs

Minimum  $\tau = 3.02466\text{ s}$  Mean = 3.03044 s  
 Maximum  $\tau = 3.03808\text{ s}$  Standard Deviation = 0.00254 s

#### 96HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where B = 57875.36 m

$\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Dec 7, 1986	120000	-588.00
LAST DATA POINT:	Feb 25, 1987	120000	1332.00

Number of Points: 81

Sampling Interval: 24 hrs

Minimum  $Z_{12} = 195.84\text{ m}$  Mean = 297.67 m  
 Maximum  $Z_{12} = 378.48\text{ m}$  Standard Deviation = 0.0047 m

**Table 7. Site and Record Information for  
PIES87B3**

Serial Number: 053  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 24  
 Additional Sensors: Pressure and Temperature  
 Pressure Sensor Serial Number: 17849

POSITION: 35°37.07 N DEPTH: 2665 m  
 74°13.92 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 26, 1986	030200	EN152
RECOVERY:	Feb 28, 1987	130346	EN156

#### TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	033152	-860.4690
LAST DATA POINT:	Feb 28, 1987	130152	1405.0310

Number of Points: 4532  
 Sampling Interval: 0.5 hrs

Minimum  $\tau$  = 0.35106 s                          Mean = 0.35759 s  
 Maximum  $\tau$  = 0.36869 s    Standard Deviation = 0.00331 s

#### 40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$   
 where B = 7224.39 m  
 $\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	120000	-828.00
LAST DATA POINT:	Feb 27, 1987	060000	1374.00

Number of Points: 368  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12}$  = 245.69 m                          Mean = 430.42 m  
 Maximum  $Z_{12}$  = 529.52 m    Standard Deviation = 61.07 m

### PIES87B3 (continue)

#### MEASURED PRESSURE RECORDS

Fig. 4

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	033152	-860.4690
LAST DATA POINT:	Feb 28, 1987	130152	1405.0310

Number of Points: 4532

Sampling Interval: 0.5 hrs

Minimum = 2707.75 dbar                          Mean = 2708.47 dbar  
 Maximum = 2709.34 dbar    Standard Deviation = 0.33335 dbar

#### RESIDUAL PRESSURE RECORDS

Fig. 5

$$P_{\text{residual}} = P_{\text{measured}} - \text{MEAN} - \text{DRIFT} - \text{TIDE}$$

$$\text{DRIFT} = P_1[1 - \exp(-P_2 t)] + P_3$$

where  $t$  = Time of sample in hours, starting with  
 $t = 13.0$  hrs for the first data point

$$P_1 = 0.8711981 \text{ dbar}$$

$$P_2 = 0.0000230 \text{ dbar}$$

$$P_3 = 0.0237850 \text{ dbar}$$

TIDE calculated from the following constituents:

	M2	N2	S2	K2	K1	O1	P1	Q1
H (dbar):	.43050	.10010	.08999	.02143	.09059	.07073	.02959	.01645
G°:	353.13	335.75	19.66	21.12	183.03	187.32	184.32	180.85

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	153152	-848.4688
LAST DATA POINT:	Feb 28, 1987	130152	1405.0312

Number of Points: 4508

Sampling Interval: 0.5 hrs

Minimum = -0.1532 dbar                          Mean = -0.0001 dbar  
 Maximum = 0.1229 dbar    Standard Deviation = 0.0350 dbar

**PIES87B3 (continue)****40HRLP PRESSURE RECORDS**

Fig. 8

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000000	-816.0000
LAST DATA POINT:	Feb 27, 1987	060000	1374.0000

Number of Points: 366  
 Sampling Interval: 6.0 hrs

Minimum = -0.1216 dbar                    Mean = 0.0009 dbar  
 Maximum = 0.0719 dbar   Standard Deviation = 0.0294 dbar

**TEMPERATURE RECORDS**

Fig. 6

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	033152	-860.4690
LAST DATA POINT:	Feb 28, 1987	130152	1405.0310

Number of Points: 4532  
 Sampling Interval: 0.5 hrs

Minimum = 2.570 °C                    Mean = 2.837 °C  
 Maximum = 3.088 °C   Standard Deviation = 0.124 °C

**40HRLP TEMPERATURE RECORDS**

Fig. 9

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000000	-816.0000
LAST DATA POINT:	Feb 27, 1987	060000	1374.0000

Number of Points: 366  
 Sampling Interval: 6.0 hrs

Minimum = 2.578 °C                    Mean = 2.834 °C  
 Maximum = 3.063 °C   Standard Deviation = 0.114 °C

**Table 8. Site and Record Information for  
ATM87B4**

Serial Number: 063

Type of Travel Time Detector: TTD

Number of Pings per Sampling: refer to Sec. 1.5

Additional Sensors: None

POSITION: 35°26.50 N DEPTH: 3085 m  
73°59.47 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 24, 1986	062400	EN152
RECOVERY:	Feb 28, 1987	164900	EN156

**RAW TRAVEL TIME RECORDS**

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 30, 1986	112611	-756.5635
LAST DATA POINT:	Feb 21, 1987	052611	1229.4365

Number of Points: 332

Sampling Interval: 6.0 hrs

Minimum  $\tau$  = 4.07544 s                          Mean = 4.07870 s  
Maximum  $\tau$  = 4.08579 s   Standard Deviation = 0.01749 s

**96HRLP THERMOCLINE DEPTH RECORDS**

Fig. 7.2

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where B = 78181.09 m

$\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Dec 2, 1986	120000	-708.00
LAST DATA POINT:	Feb 18, 1987	120000	1'64.00

Number of Points: 79

Sampling Interval: 24 hrs

Minimum  $Z_{12}$  = 562.65 m                          Mean = 684.56 m  
Maximum  $Z_{12}$  = 732.31 m   Standard Deviation = 0.0034 m

**Table 9. Site and Record Information for  
IES87B5**

Serial Number: 052  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 20  
 Additional Sensors: None

POSITION:  $35^{\circ}22.06\text{ N}$  DEPTH: 3280 m  
 $73^{\circ}53.06\text{ W}$

	DATE	GMT	CRUISE
LAUNCH:	Nov 26, 1986	175600	EN152
RECOVERY:	Feb 28, 1987	164500	EN156

**TRAVEL TIME RECORDS**  
 Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 26, 1986	183135	-845.4736
LAST DATA POINT:	Feb 28, 1987	163133	1408.5258

Number of Points: 4509  
 Sampling Interval: 0.5 hrs

Minimum  $\tau = 4.36937\text{ s}$  Mean = 4.37362 s  
 Maximum  $\tau = 4.37918\text{ s}$  Standard Deviation = 0.00130 s

**40HRLP THERMOCLINE DEPTH RECORDS**  
 Fig. 7.2

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$   
 where B = 83818.94 m  
 $\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	000000	-816.00
LAST DATA POINT:	Feb 27, 1987	060000	1374.00

Number of Points: 366  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12} = 641.63\text{ m}$  Mean = 719.65 m  
 Maximum  $Z_{12} = 775.03\text{ m}$  Standard Deviation = 21.17 m

**Table 10. Site and Record Information for  
PIES87B6**

Serial Number: 054

Type of Travel Time Detector: TTC

Number of Pings per Sampling: 24

Additional Sensors: Pressure and Temperature

Pressure Sensor Serial Number: 18426

POSITION: 35°14.54 N DEPTH: 3555 m  
73°42.92 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	032900	EN152
RECOVERY:	Feb 28, 1987	211200	EN156

**TRAVEL TIME RECORDS**

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	043220	-835.4612
LAST DATA POINT:	Feb 28, 1987	210220	1413.0388

Number of Points: 4498

Sampling Interval: 0.5 hrs

Minimum  $\tau$  = 0.34298 s                          Mean = 0.34741 s  
Maximum  $\tau$  = 0.35101 s   Standard Deviation = 0.00117 s

**40HRLP THERMOCLINE DEPTH RECORDS**

Fig. 7.2

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$

where B = 7365.00 m

$\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	120000	-804.00
LAST DATA POINT:	Feb 27, 1987	120000	1380.00

Number of Points: 365

Sampling Interval: 6.0 hrs

Minimum  $Z_{12}$  = 719.31 m                          Mean = 763.74 m  
Maximum  $Z_{12}$  = 810.76 m   Standard Deviation = 18.88 m

**PIES87B6 (continue)****MEASURED PRESSURE RECORDS**

Fig. 4

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	043220	-835.4612
LAST DATA POINT:	Feb 28, 1987	210220	1413.0388

Number of Points: 4498  
 Sampling Interval: 0.5 hrs

( Pressure record is jumpy )

**TEMPERATURE RECORDS**

Fig. 6

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	043220	-835.4612
LAST DATA POINT:	Feb 28, 1987	210220	1413.0388

Number of Points: 4498  
 Sampling Interval: 0.5 hrs

Minimum = 2.324 °C                    Mean = 2.372 °C  
 Maximum = 2.458 °C   Standard Deviation = 0.045 °C

**40HRLP TEMPERATURE RECORDS**

Fig. 9

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	000000	-792.0000
LAST DATA POINT:	Feb 27, 1987	120000	1380.0000

Number of Points: 363  
 Sampling Interval: 6.0 hrs

Minimum = 2.324 °C                    Mean = 2.372 °C  
 Maximum = 2.442 °C   Standard Deviation = 0.030 °C

**Table 11. Site and Record Information for  
IES87B7**

Serial Number: 036  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 20  
 Additional Sensors: None

POSITION: 35°06.05 N DEPTH: 3800 m  
 73°31.94 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	080900	EN152
RECOVERY:	Mar 1, 1987	001700	EN156

#### TRAVEL TIME RECORDS

Fig. 3.2

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	090135	-830.9736
LAST DATA POINT:	Mar 1, 1987	000133	1416.0258

Number of Points: 4495  
 Sampling Interval: 0.5 hrs

Minimum  $\tau = 5.07445$  s                          Mean = 5.07846 s  
 Maximum  $\tau = 5.08267$  s   Standard Deviation = 0.001394 s

#### 40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.2

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$   
 where B = 97250.04 m  
 $\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 28, 1986	180000	-798.00
LAST DATA POINT:	Feb 27, 1987	120000	1386.00

Number of Points: 365  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12} = 713.03$  m                          Mean = 758.96 m  
 Maximum  $Z_{12} = 807.02$  m   Standard Deviation = 22.45 m

**Table 12. Site and Record Information for  
IES87C1**

Serial Number: 041  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 20  
 Additional Sensors: None

POSITION: 36°02.80 N DEPTH: 2880 m  
 73°52.90 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 23, 1986	060700	EN152
RECOVERY:	Mar 3, 1987	044800	EN156

#### TRAVEL TIME RECORDS

Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 23, 1986	064635	-929.2236
LAST DATA POINT:	Dec 24, 1986	064635	-185.2236

Number of Points: 1489  
 Sampling Interval: 0.5 hrs

Minimum  $\tau$  = 3.94585 s                          Mean = 3.95146 s  
 Maximum  $\tau$  = 3.95906 s    Standard Deviation = 0.00259 s

#### 40HRLP THERMOCLINE DEPTH RECORDS

Fig. 7.1

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$   
 where B = 75455.93 m  
 $\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 24, 1986	180000	-894.00
LAST DATA POINT:	Dec 23, 1986	000000	-216.00

Number of Points: 114  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12}$  = 274.26 m                          Mean = 373.72 m  
 Maximum  $Z_{12}$  = 460.27 m    Standard Deviation = 44.67 m

**Table 13. Site and Record Information for  
IES87C2**

Serial Number: 061  
 Type of Travel Time Detector: TTC  
 Number of Pings per Sampling: 20  
 Additional Sensors: None

POSITION: 35°43.98 N DEPTH: 3535 m  
 73°29.98 W

	DATE	GMT	CRUISE
LAUNCH:	Nov 27, 1986	141200	EN152
RECOVERY:	Mar 3, 1987	220600	EN156

**TRAVEL TIME RECORDS**

Fig. 3.1

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 27, 1986	151635	-824.7236
LAST DATA POINT:	Mar 3, 1987	214633	1485.7758

Number of Points: 4622  
 Sampling Interval: 0.5 hrs

Minimum  $\tau$  = 4.71669 s                          Mean = 4.72040 s  
 Maximum  $\tau$  = 4.73019 s    Standard Deviation = 0.00216 s

**40HRLP THERMOCLINE DEPTH RECORDS**

Fig. 7.1

$Z_{12}$  Conversion equation:  $Z_{12} = -19000\text{ms}^{-1} \cdot \tau_d + B$   
 where B = 90375.20 m  
 $\tau_d$  = Travel Time (sec) with tide removed

	DATE	GMT	YEARHOUR
1st DATA POINT:	Nov 29, 1986	000000	-792.00
LAST DATA POINT:	Mar 2, 1987	120000	1452.00

Number of Points: 375  
 Sampling Interval: 6.0 hrs

Minimum  $Z_{12}$  = 514.61 m                          Mean = 687.47 m  
 Maximum  $Z_{12}$  = 731.10 m    Standard Deviation = 39.48 m

### 3 Half-hourly Data For Each Cross-stream Line

Plots of the travel time records from each instrument are presented first. These are followed by the measured and residual pressure records and the temperature data for the instruments which had those additional sensors.

These are grouped by cross-stream line, with the northwesternmost IES on each line plotted at the top of the figure. Each plot is labelled with the instrument name in the upper left corner. The time scale is the same for all plots, with each increment corresponding to 5 days. The axis begins on 1200 GMT of the first date labelled.

Vertical scale for each variable is consistent between instruments. Each increment corresponds to 5 msec for the travel time records, to 0.5 dbar for the measured bottom pressure measurements, to 0.05 dbar for the residual bottom pressure data, and to 0.1°C for the temperatures.

The sampling interval of the IESs and PIESSs is normally 0.5 hours; the actual interval for each instrument is listed Section 2. ATMs have a 6 hour sampling interval. The length and the start and end times of the data records are also listed in the previous section.

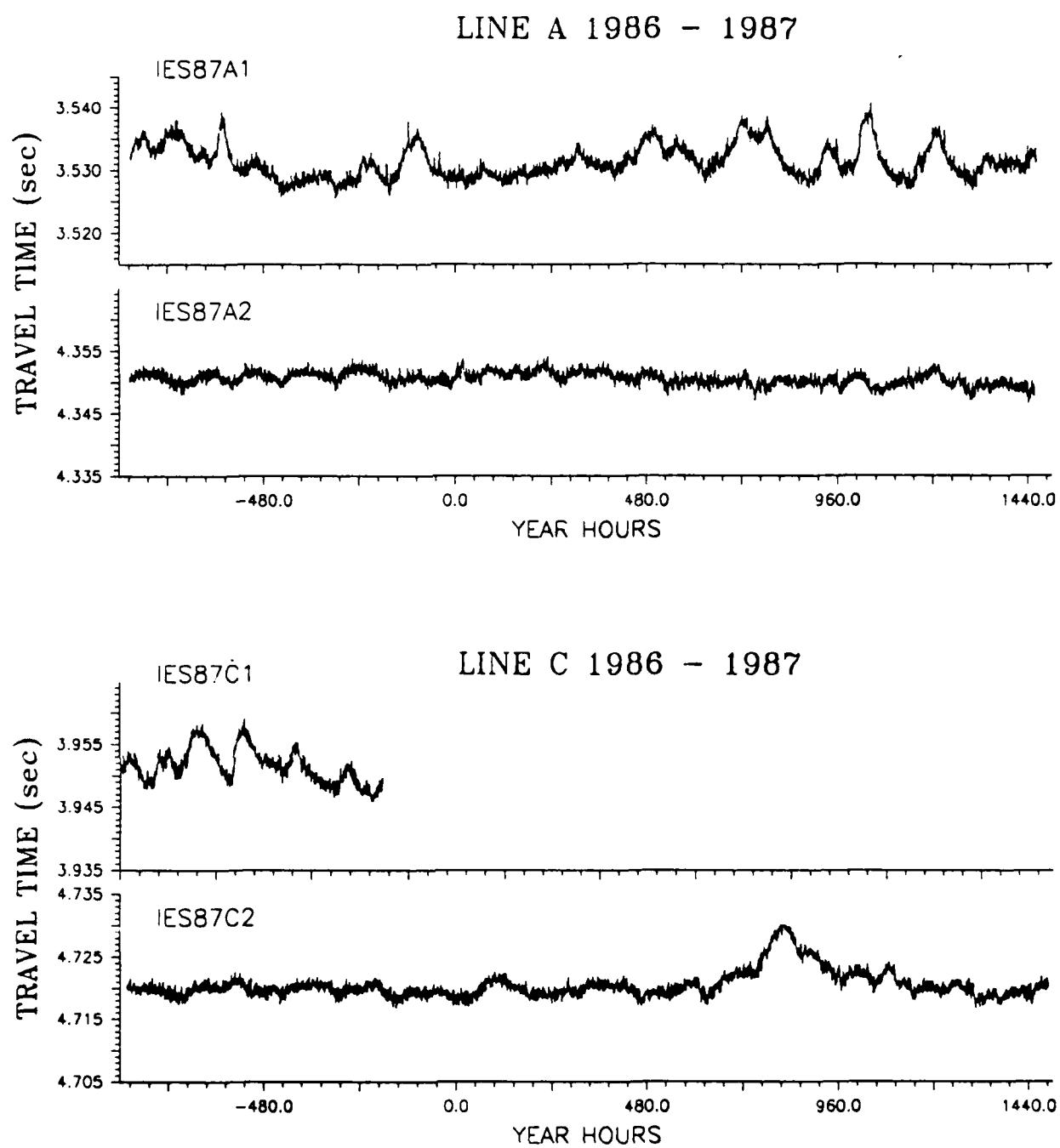


Figure 3.1: Travel time records for Line A and C at half-hourly intervals. The start and end times and records lengths are listed in Section 2.

## LINE B 1986 - 1987

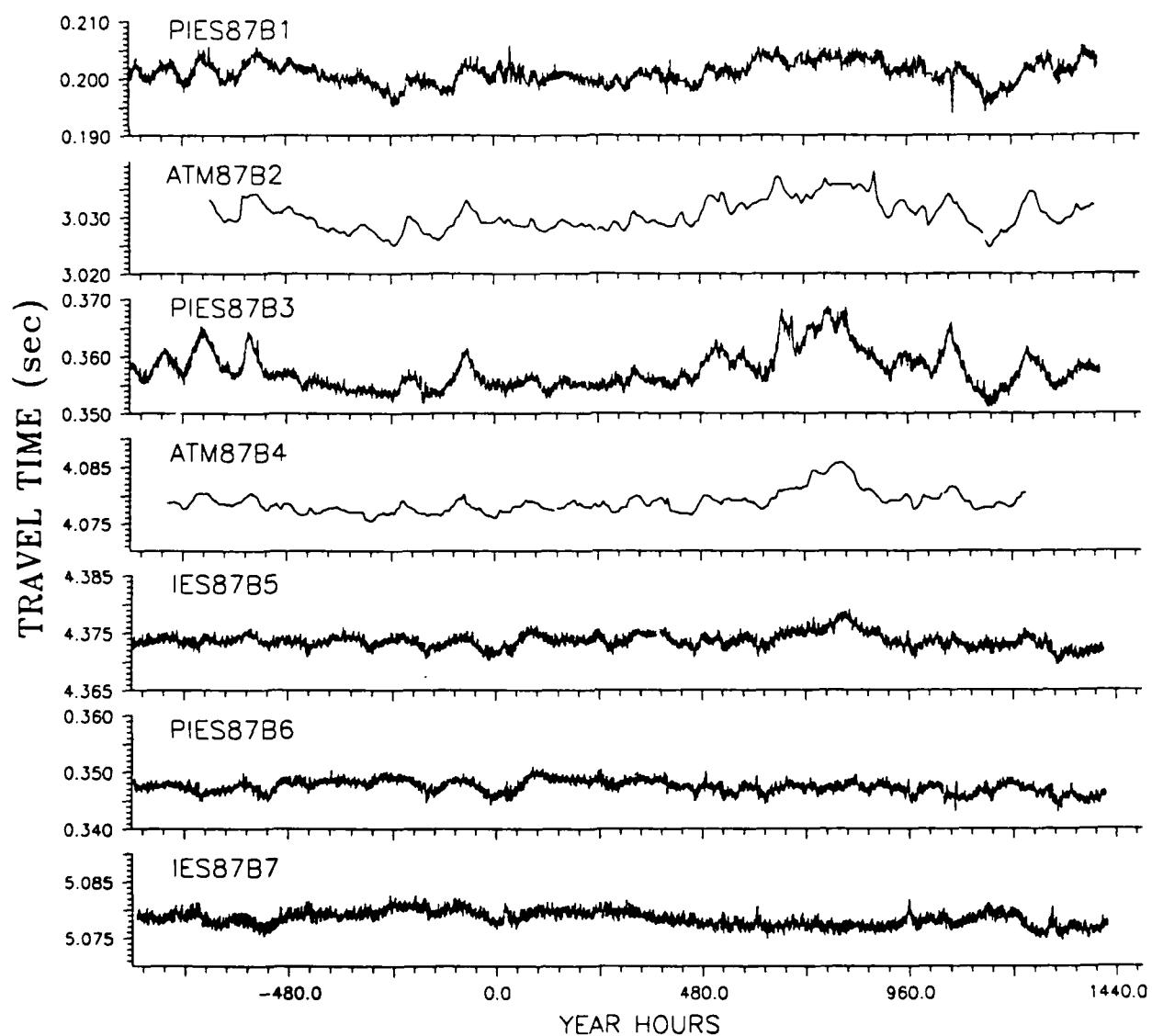


Figure 3.2: Travel time records for Line B at half-hourly intervals: at six-hourly intervals for A.M.s.

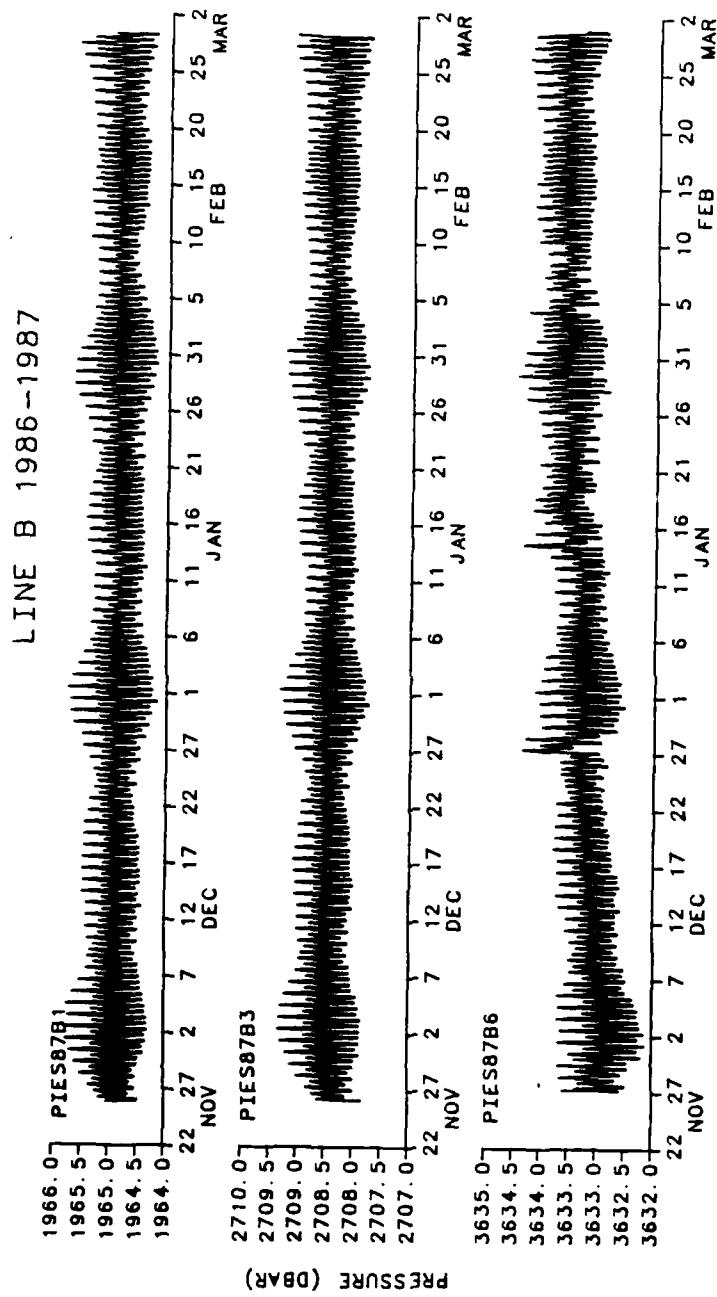
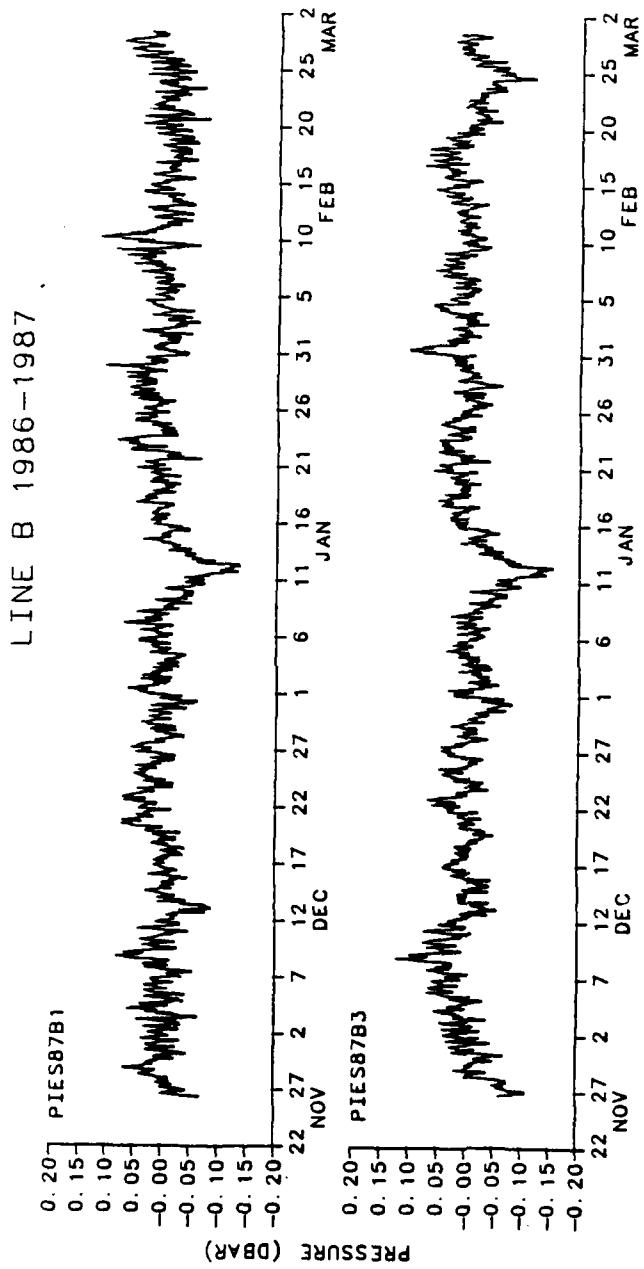


Figure 4: Half-hourly measured bottom pressure records for PIES87B1, PIES87B3 and PIES87B6. The start and end times, and records lengths are listed in Section 2.



**Figure 5:** Half-hourly residual bottom pressure records for PIERS87B1, PIERS87B3. free parameters and tidal constituents are given in Section 2.

**Figure 5:**

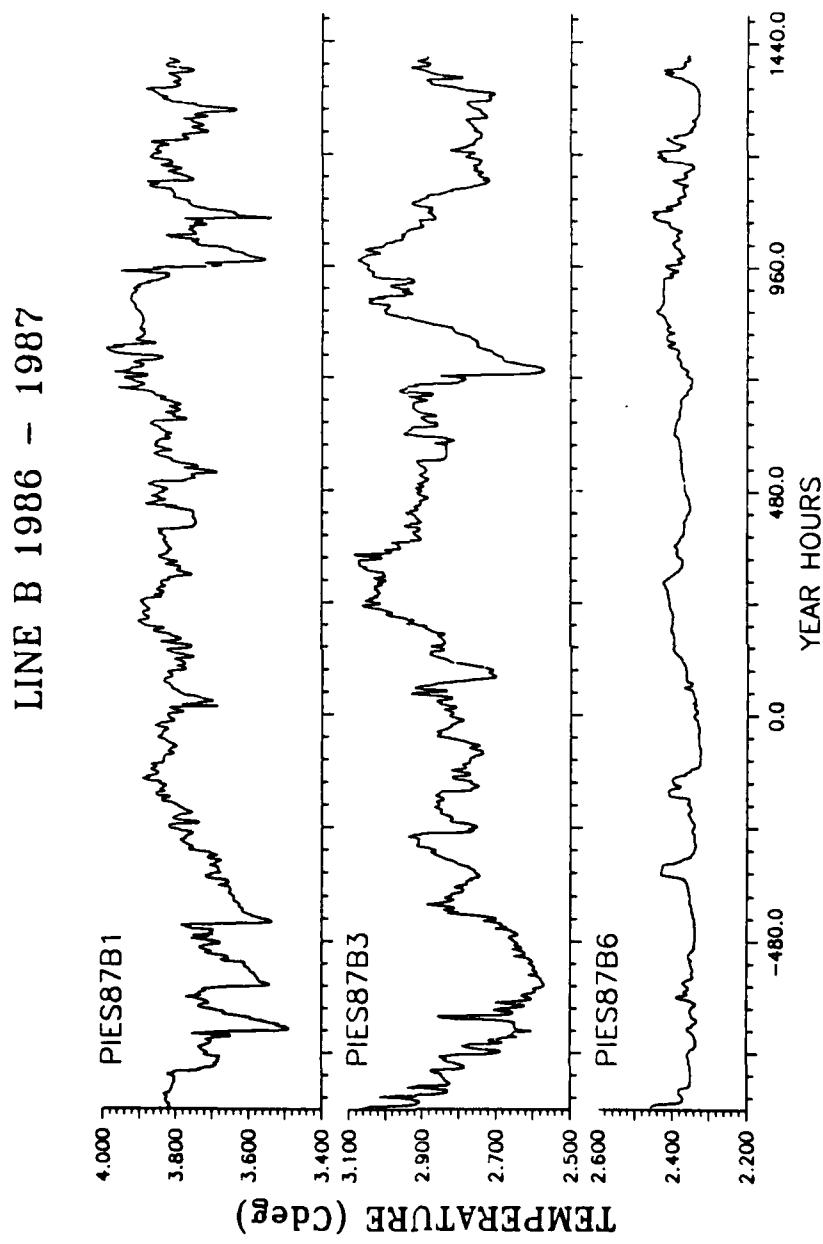


Figure 6: Half-hourly temperature records for PIERS87B1, PIERS87B3 and PIERS87B6.

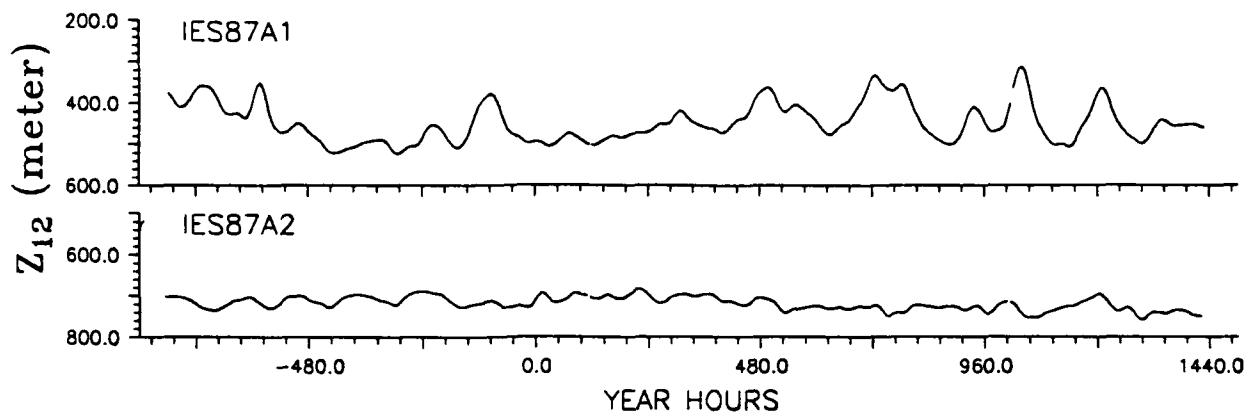
#### 4 40 HRLP Data For Each Cross-Stream Line

The low-pass filtered thermocline depth ( $Z_{12}$ ), bottom pressure and temperature records are plotted for each cross-stream line. The thermocline depth records for each cross-stream line are presented first. These are followed by the 40 HRLP residual pressure records and the 40 HRLP temperature data for the instruments which had these additional sensors.

The time scale is the same for all plots, with each increment corresponding to 10 days. The axis begins on 1200 GMT of the first date labelled.

Vertical scale for each variable is consistent between instruments. Each increment corresponds to 100 m for the  $Z_{12}$  records, to 0.05 dbar for the bottom pressure measurements, and to 0.1°C for the temperatures. The sampling intervals are 6 hours for all variables of the IESs and PIESSs and 24 hours for those of the ATMs. The length and the start and end times of the data records are tabulated in Section 2.

## LINE A 1986 - 1987



## LINE C 1986 - 1987

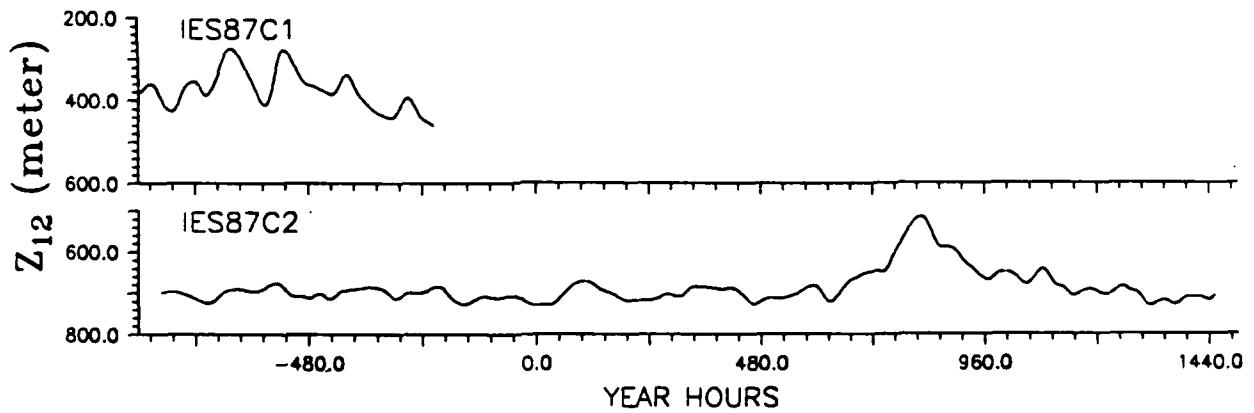


Figure 7.1: Thermocline depth records for Line A and C: records 40HR low-pass filtered at 6 hour intervals. For each instrument, the equation used to convert travel time to  $Z_{12}$  is given in Section 2.

## LINE B 1986 - 1987

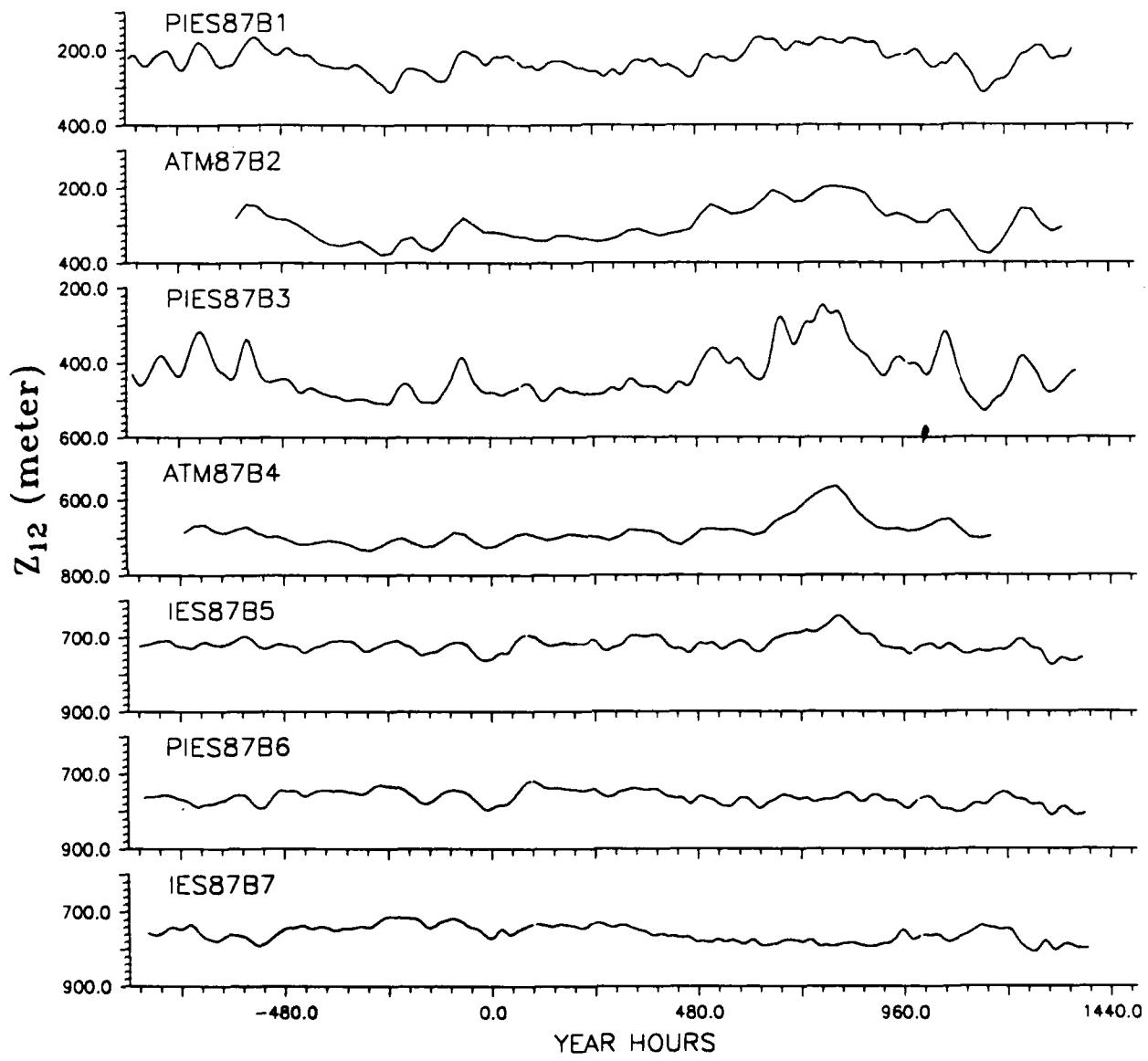


Figure 7.2: Thermocline depth records for Line B: (P)IESs records 40HR low-pass filtered at 6 hour intervals and ATM records 96HR low-pass filtered at 24 hour intervals.

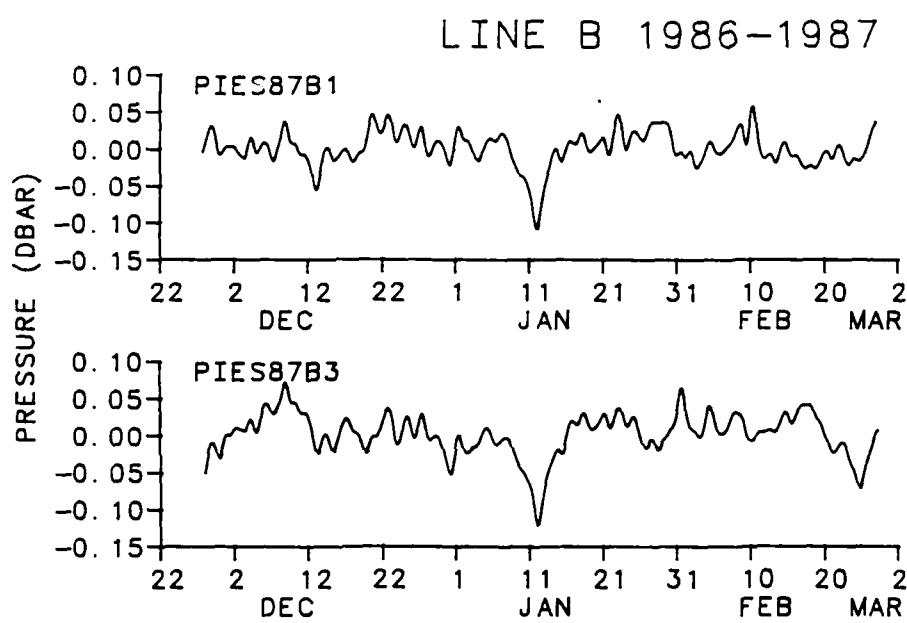
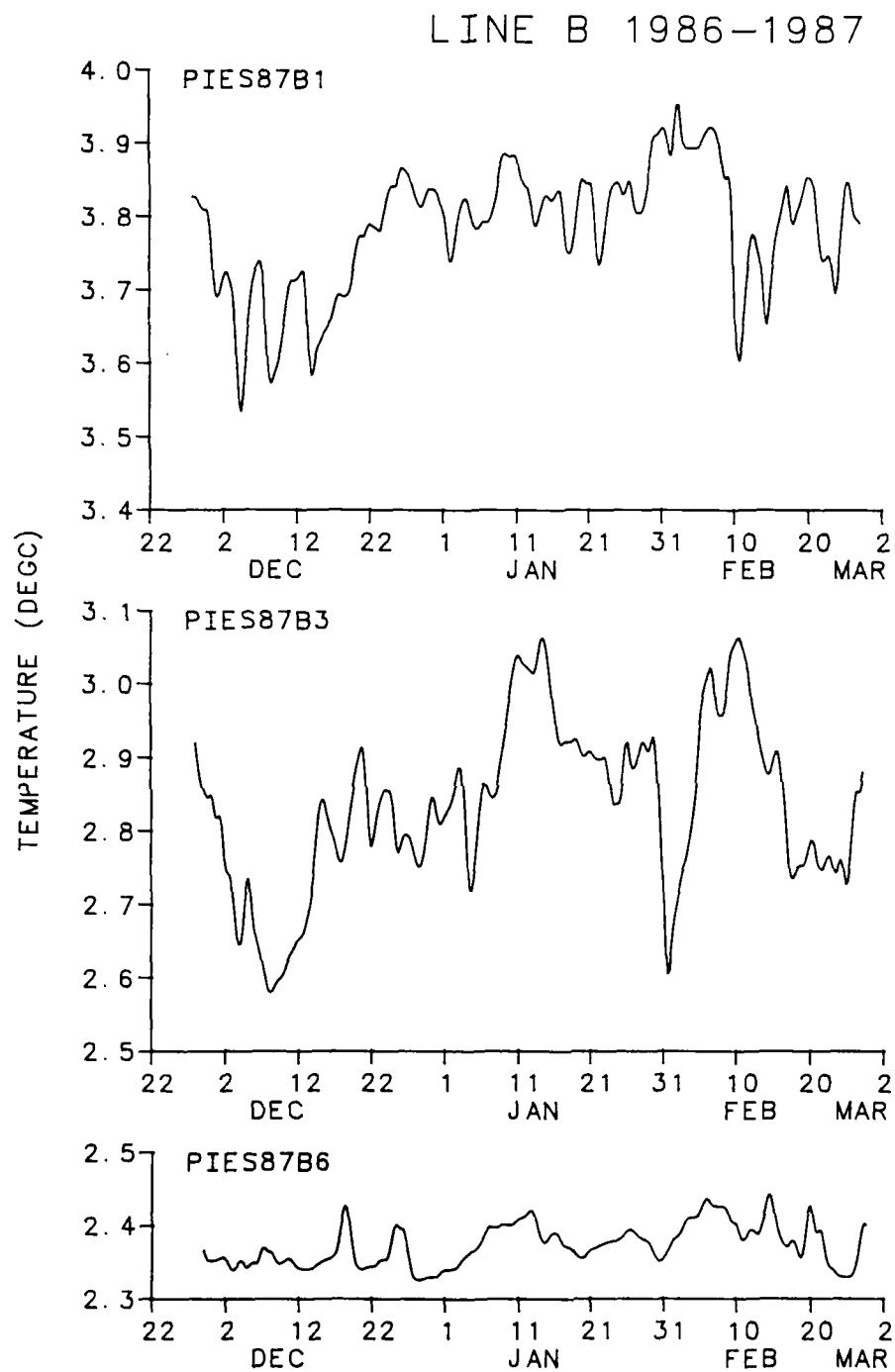


Figure 6 40HRLP bottom pressure records for PIES87B1 and PIES87B3 at 6 hour intervals.



**Figure 9: 40HRLP temperature records for PIES87B1, PIES87B3 and PIES87B6.  
at 6 hour intervals.**

## 5 Thermocline Depth Maps

Contour plots of the mean and variance fields and the error fields, the thermocline depth ( $Z_{12}$ ) fields are presented.

Each of the contoured frames corresponds to the 160 Km by 140 Km boxed region shown in Figure 1. The axes, oriented  $045^{\circ}\text{T}$ , are referenced to a grid origin located at  $35^{\circ}\text{N}$   $75^{\circ}\text{W}$ . Each frame consists of a  $9 \times 8$  square grid of points, at 20 Km spacing. The actual IES sites are indicated by the + marks and the positions are listed in Table 1.

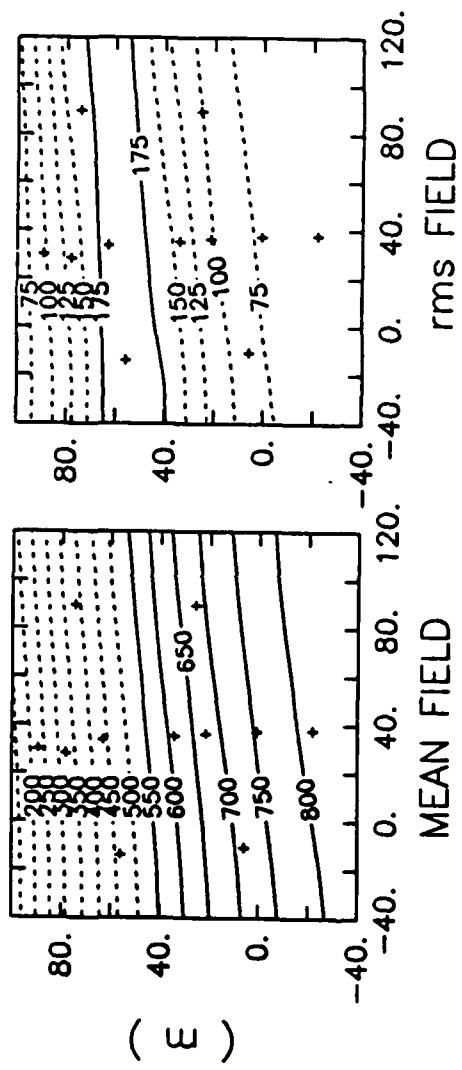


Figure 10: Mean field(left) for the 28 Nov. 1986 to 27 Feb. 1987 data and root-mean-square variance field(right) are contoured in plane view. Contour interval of the mean field is 50 m, with dashed lines indicating  $Z_{12} \leq 500$  m. Contour interval of the variance field is 25 m with the dashed region corresponding to variance  $\leq 150$  m rms.

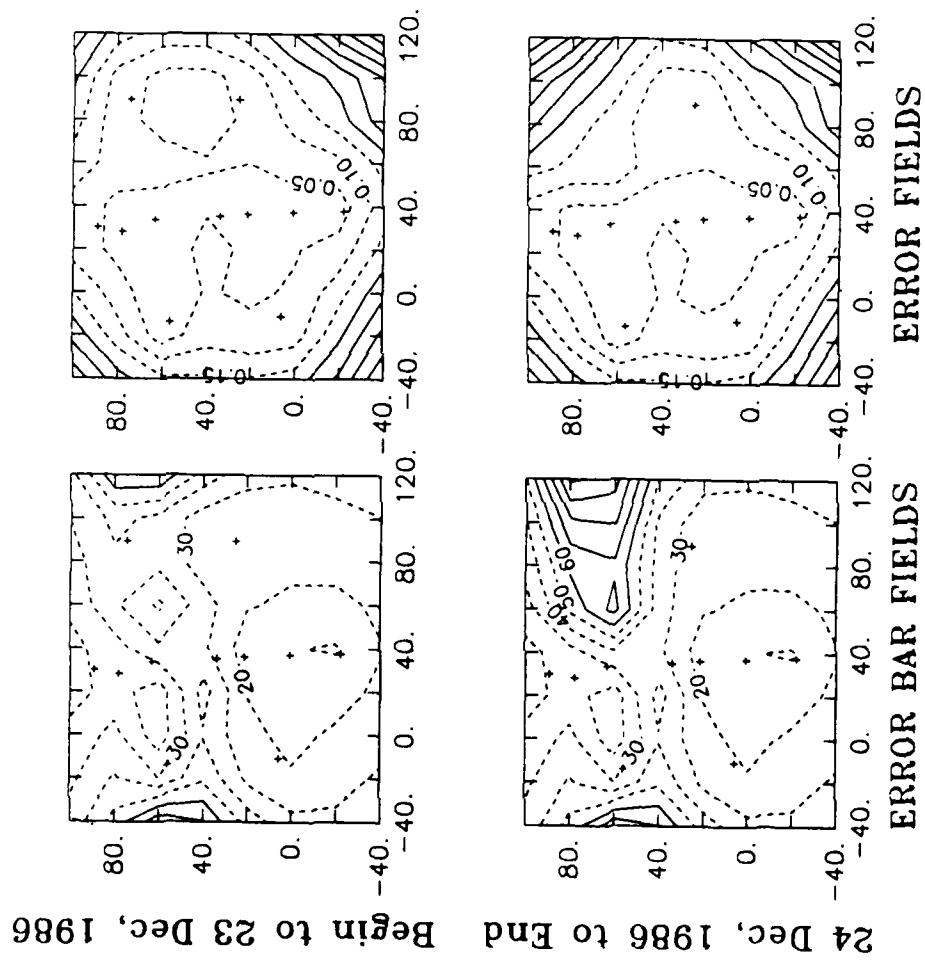
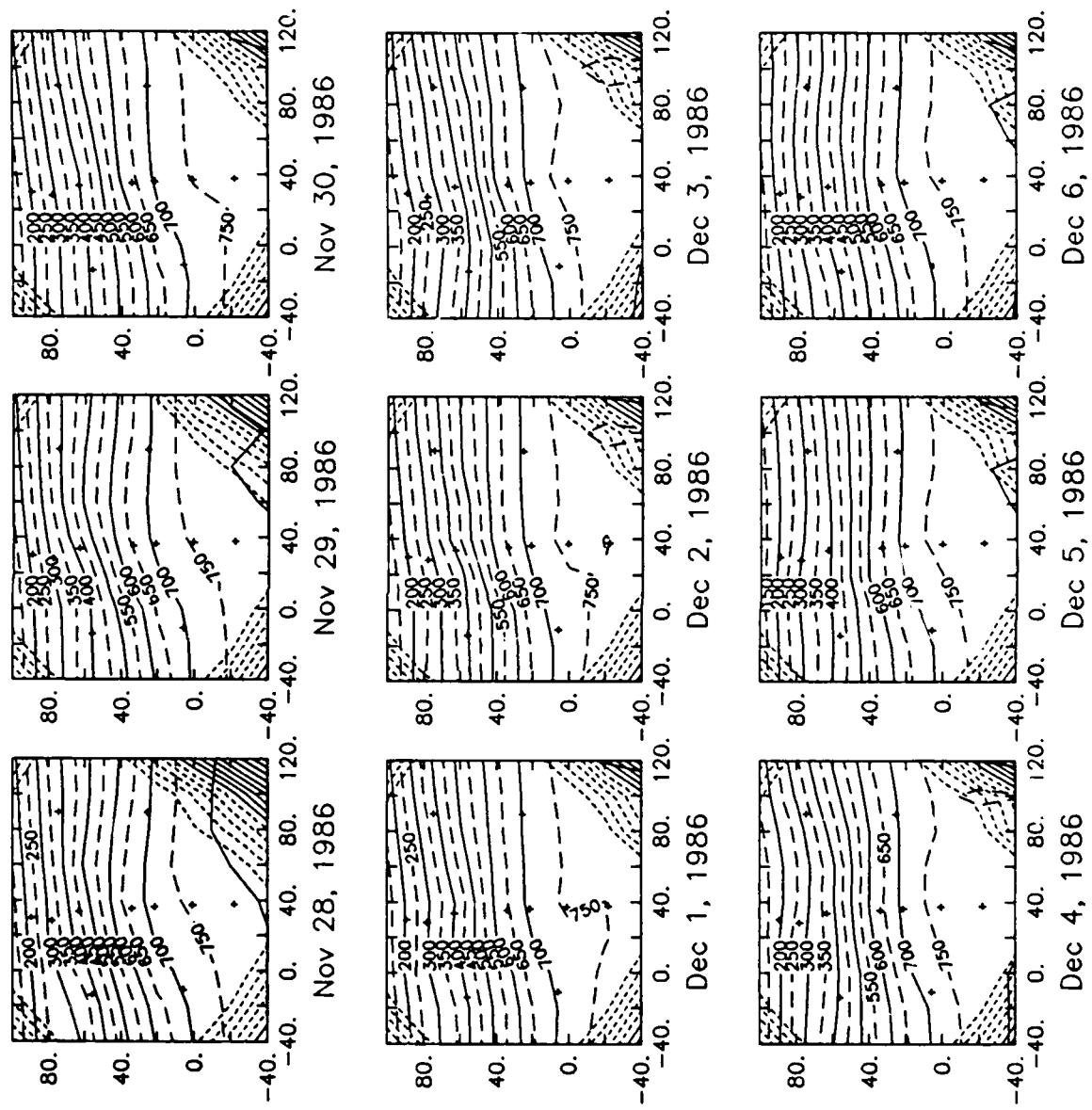
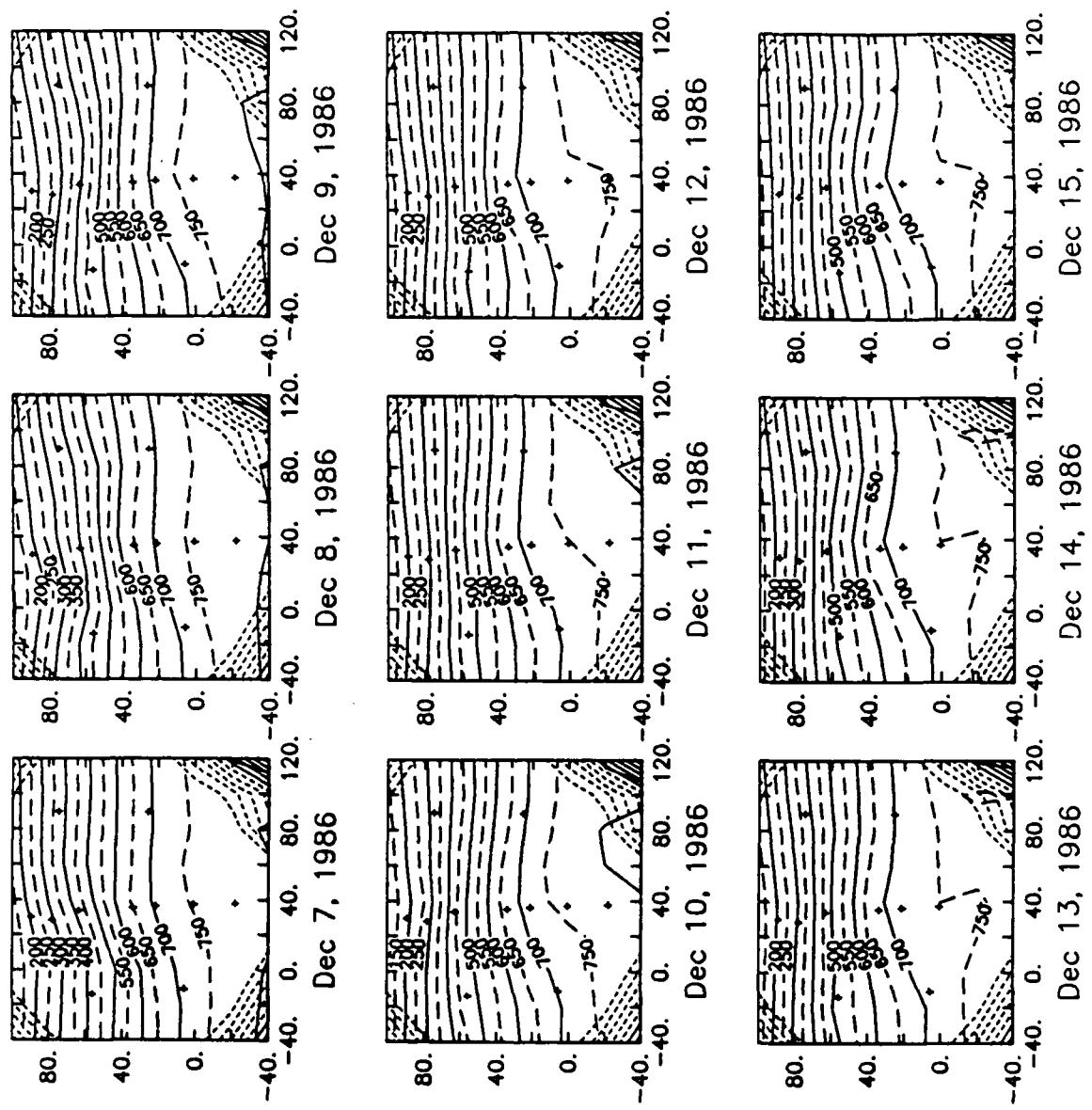


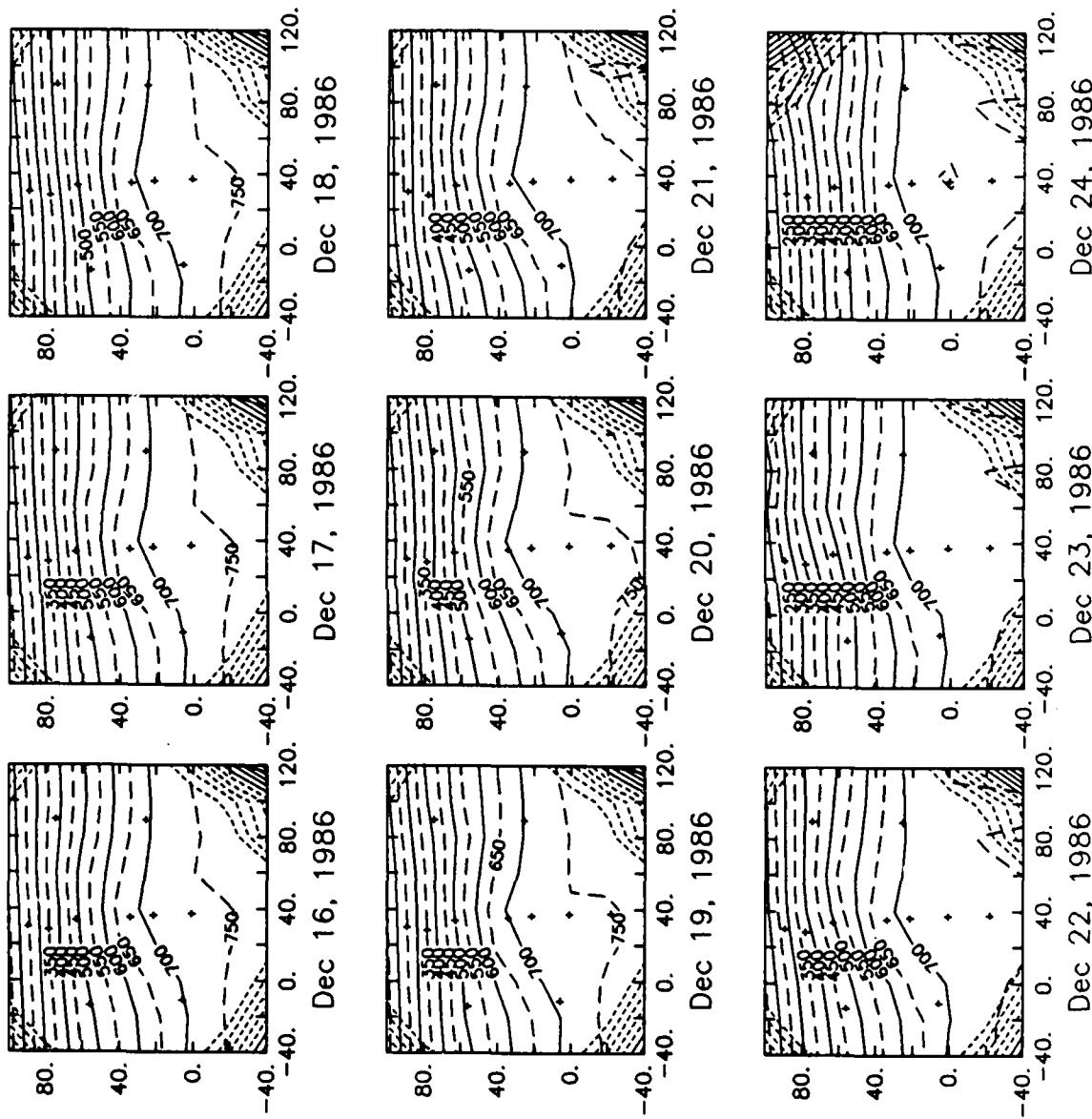
Figure 11:

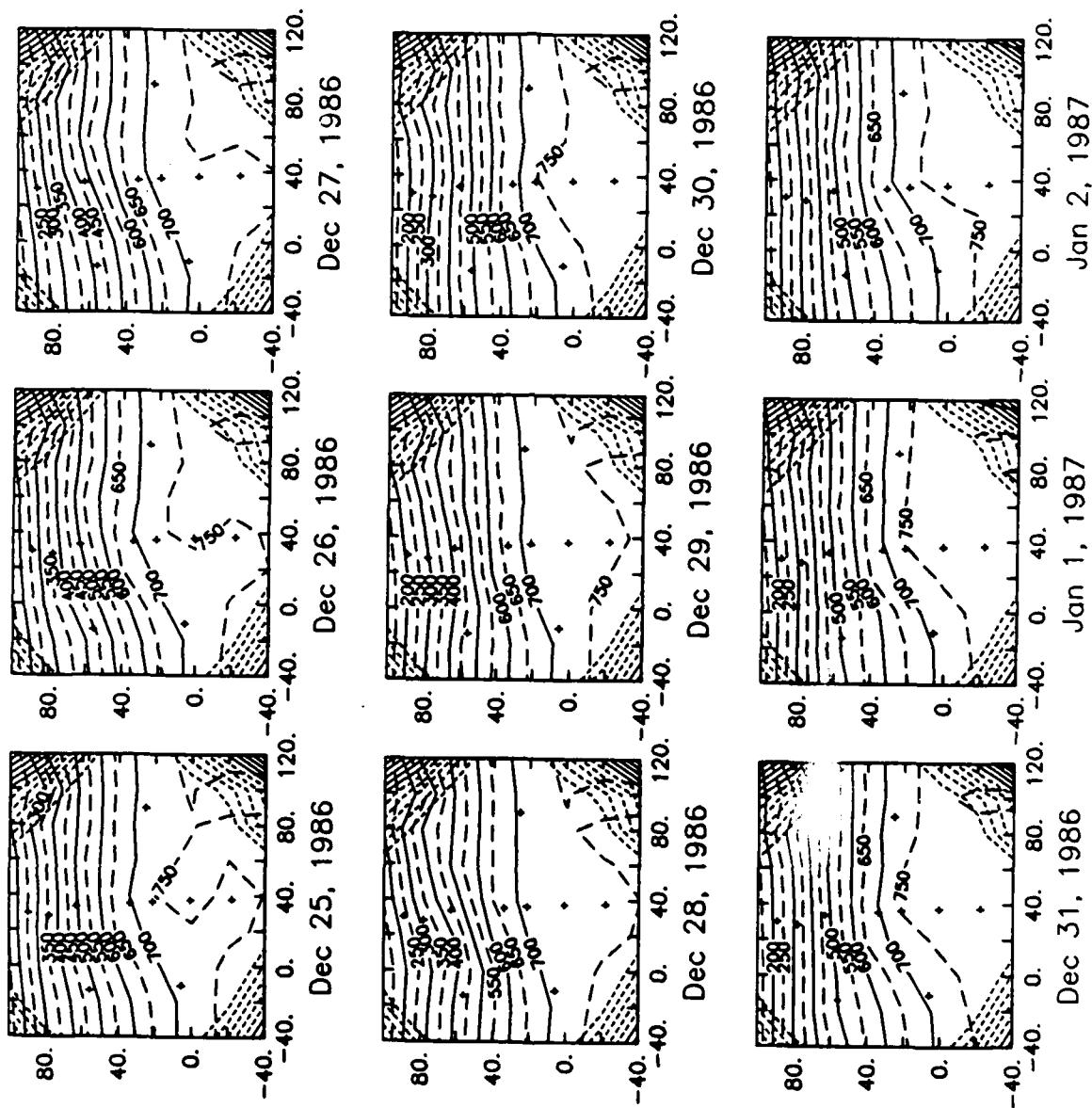
The error bar fields (left) have a contour interval of 10 m and the dashed region corresponds to errors < 50 m. The error (percent variance) fields, shown at right, are contoured at 5% intervals, with the dashed region corresponding to < 15% error. The error maps apply to the  $Z_{12}$  in Figure 12 for the dates shown.

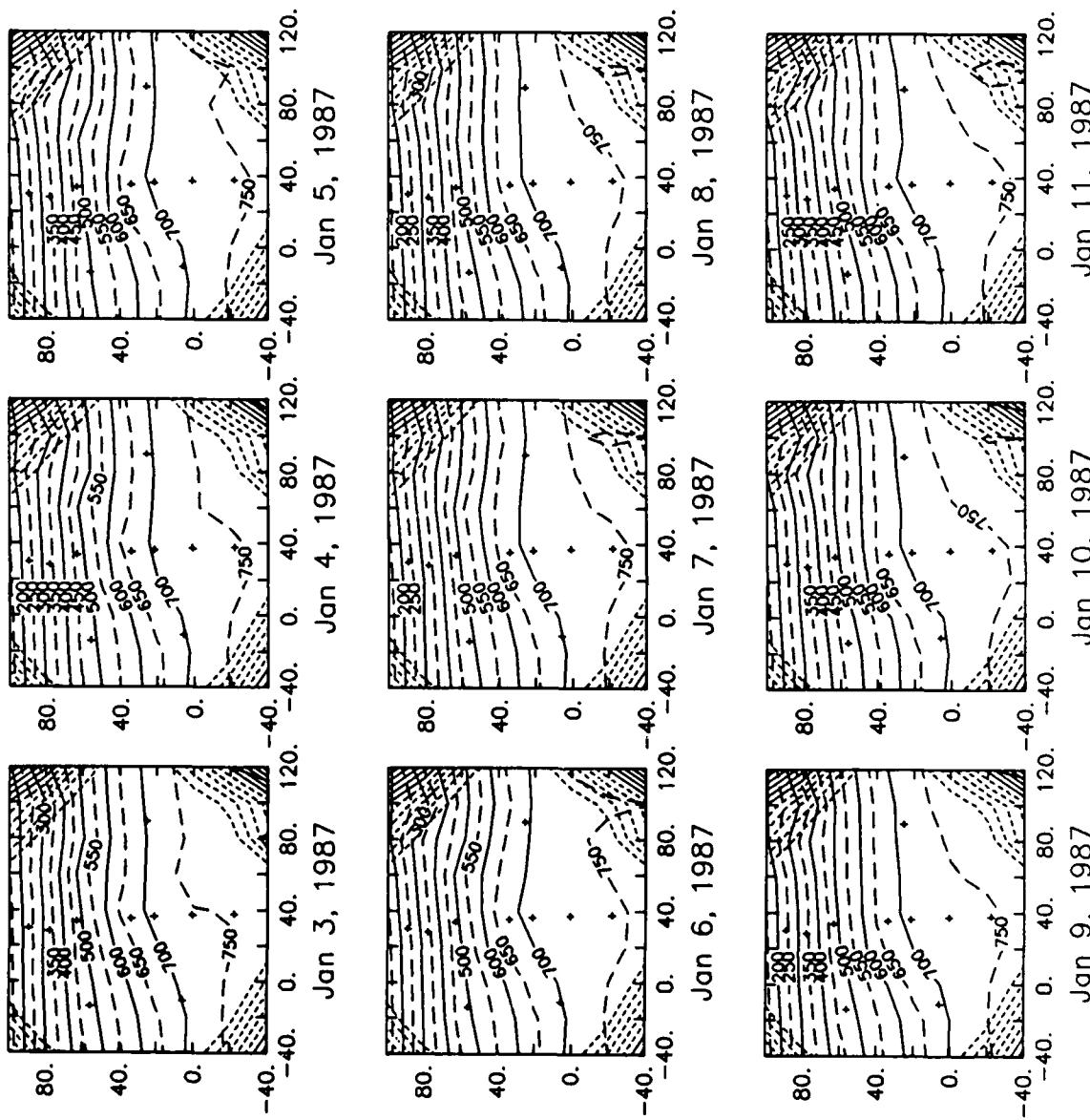
Figure 12: The  $12^{\circ}$  isotherm depth,  $Z_{12}$ , field is shown at daily intervals from 28 Nov, 1986 to 27 Feb, 1987. The maps are shown for 1200 GMT on the date indicated at the bottom. The  $Z_{12}$  field is contoured by solid and dashed lines with 100 m intervals. The shorter dashed lines correspond the error maps are shown in Figure 11.

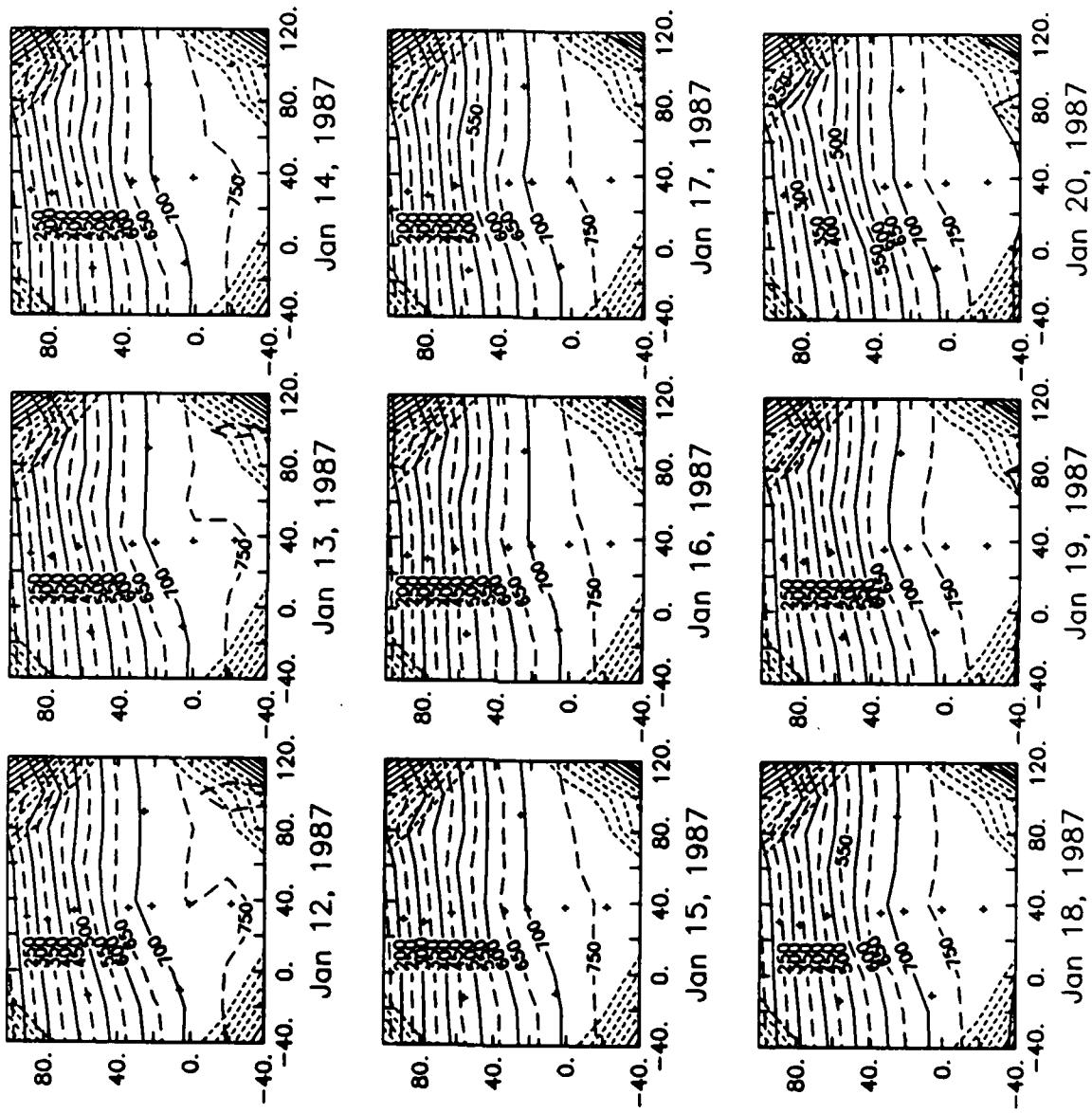


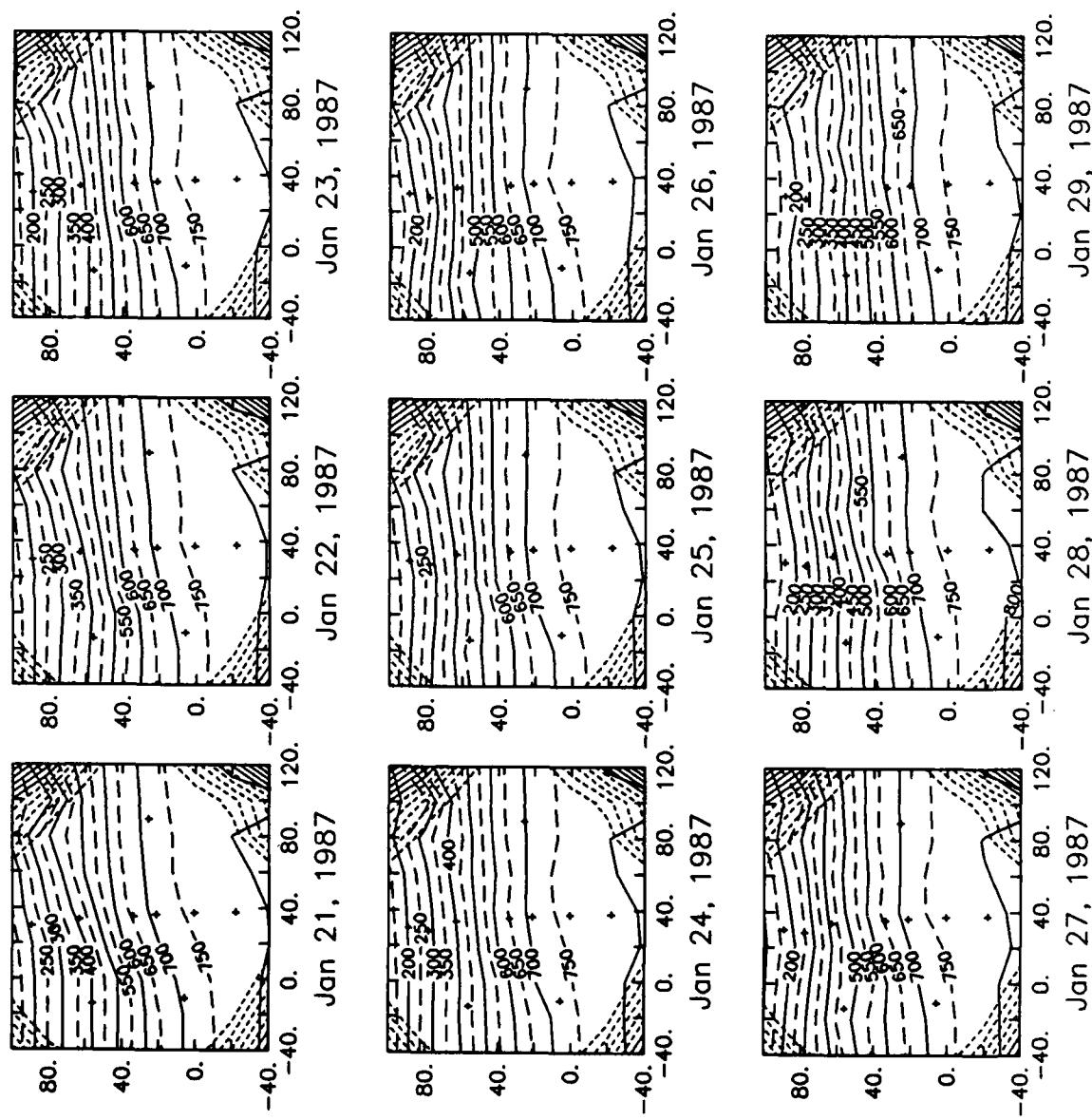


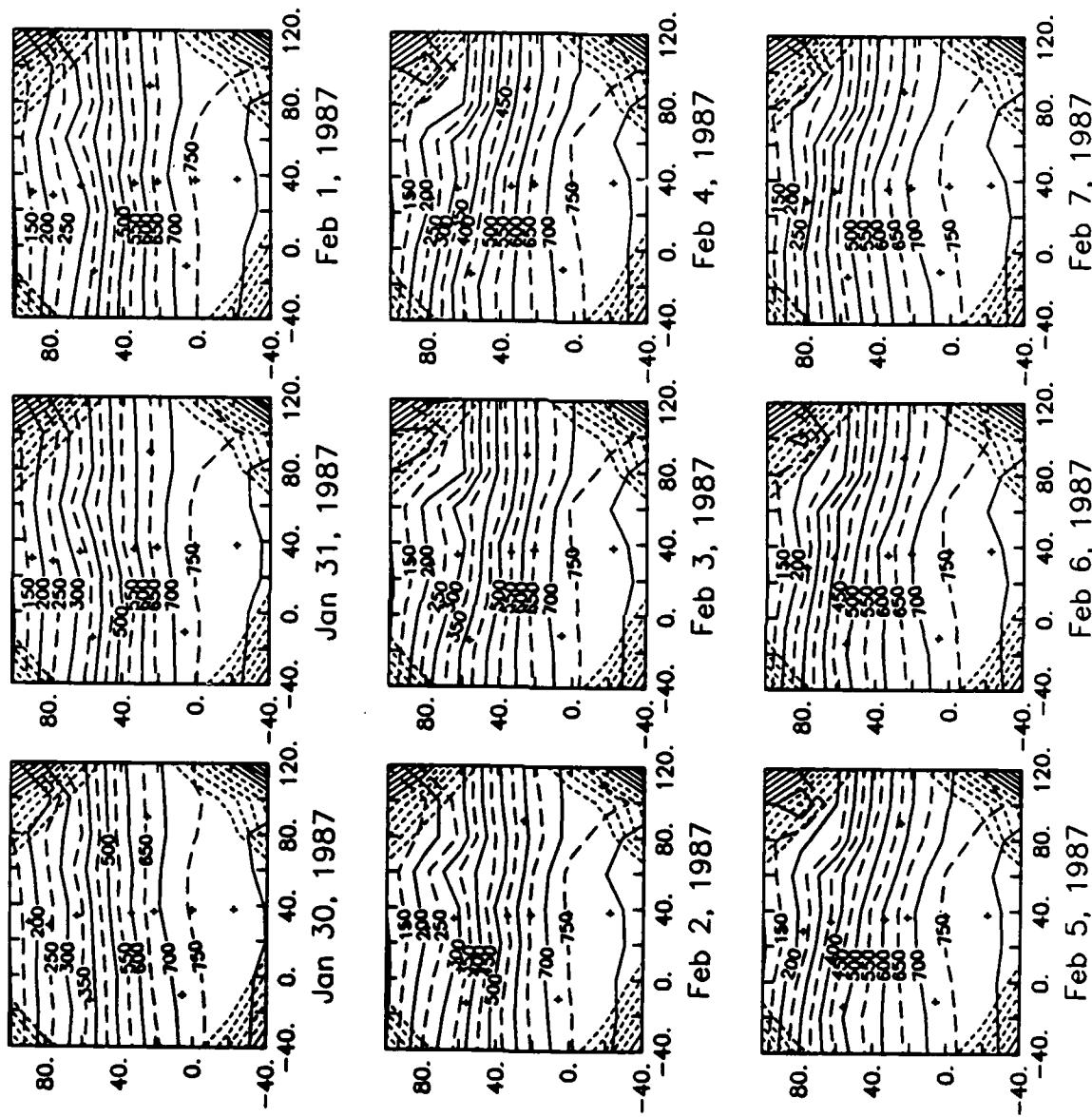


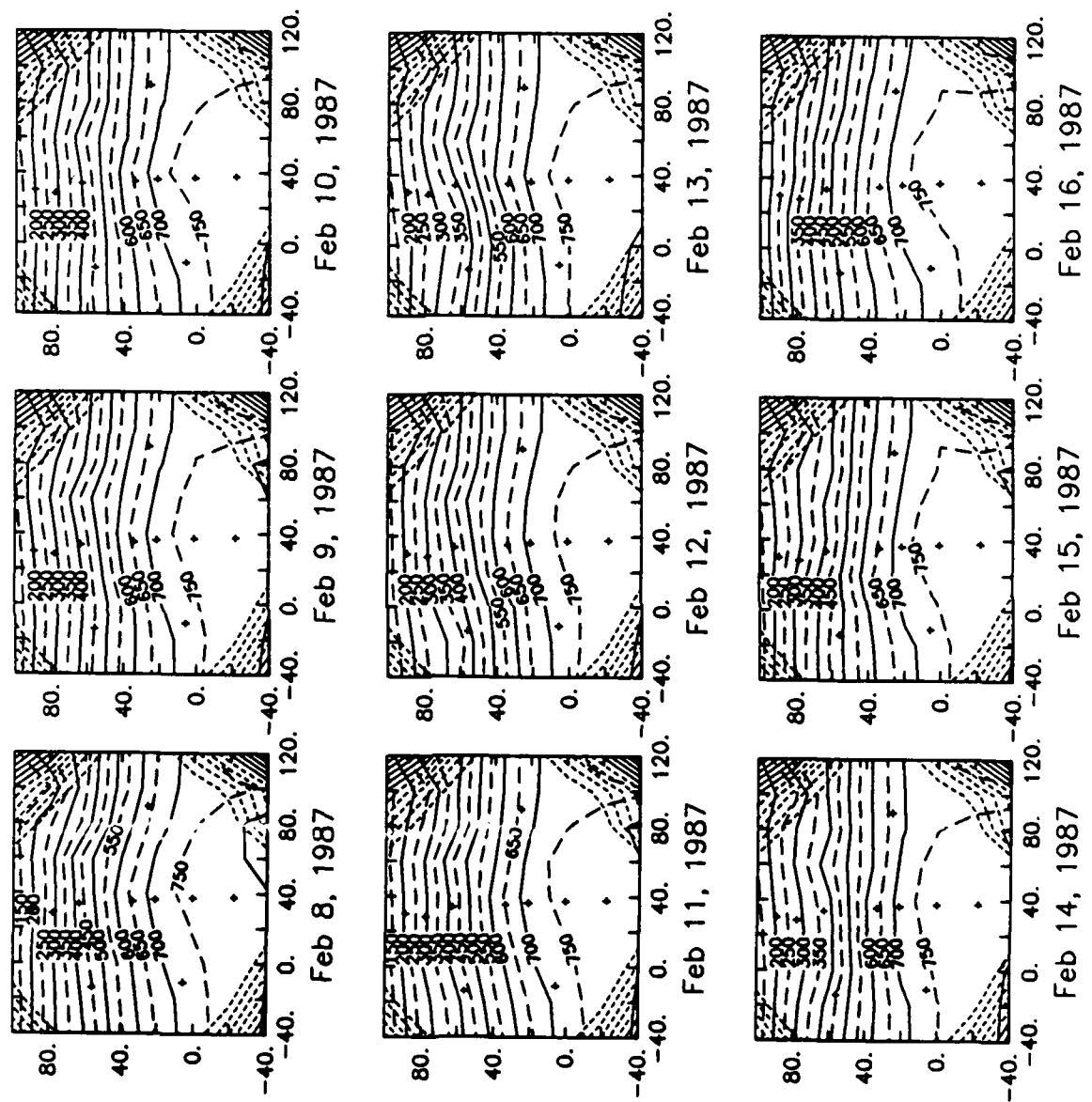


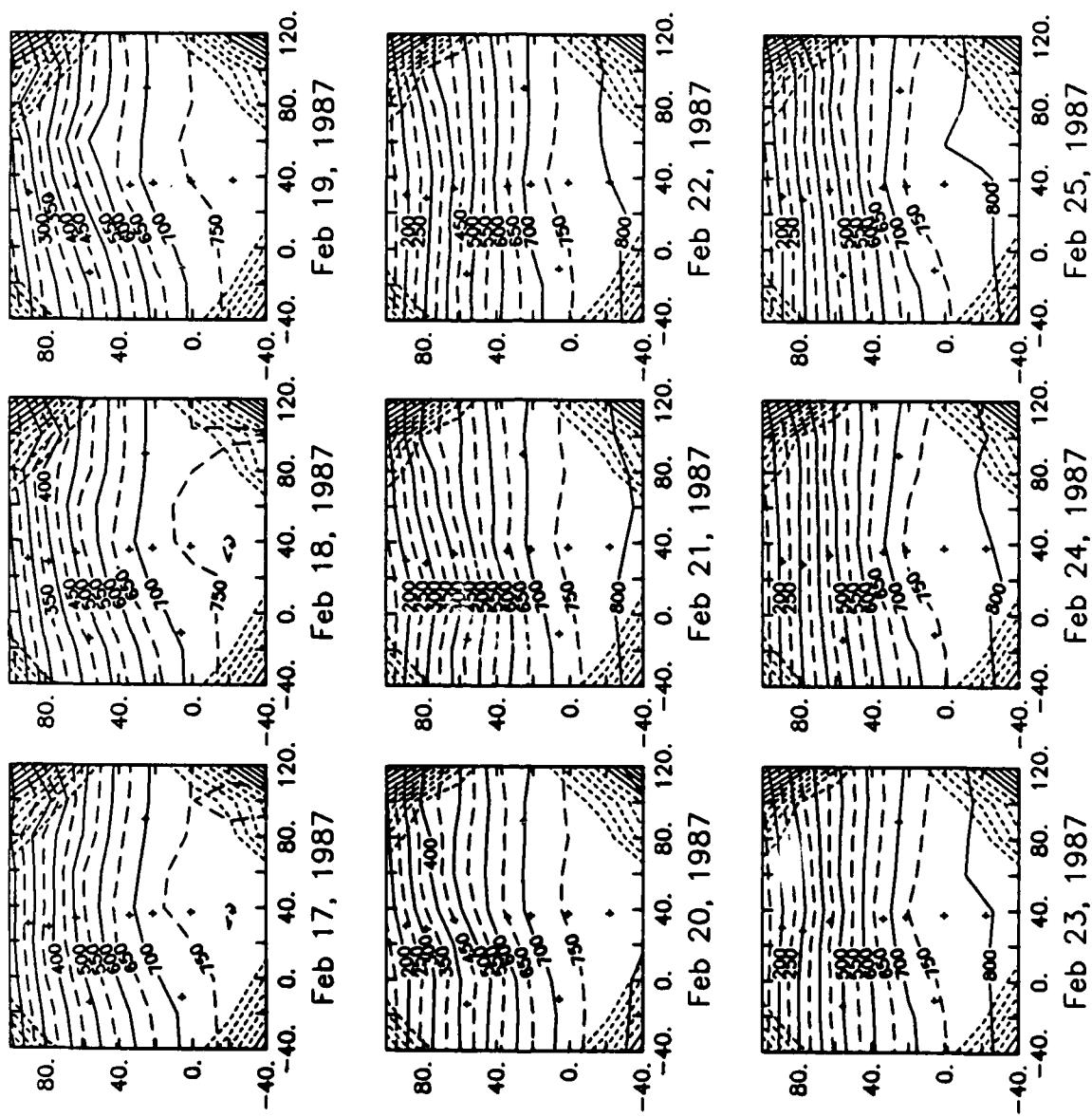


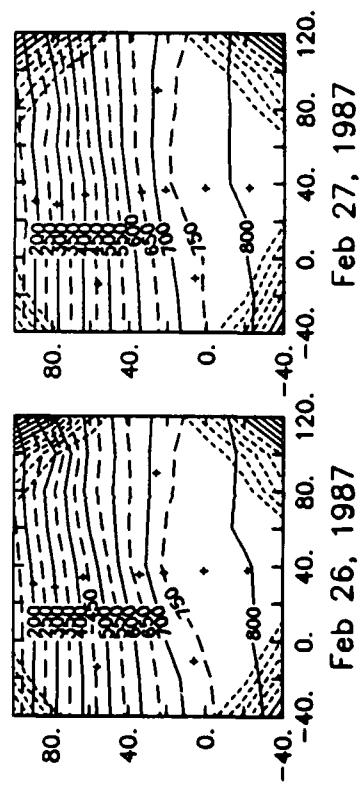












## ACKNOWLEDGMENTS

The SYNOP Pilot Experiment was supported by the Office of Naval Research under contract number N00014-86-C-0394. We thank the crews of the R/V ENDEAVOR for their efforts during the deployment and recovery cruises. The successful deployment and recovery of the inverted echo sounders is due to the instrument development and careful preparation done by Gerard Chaplin and Michael Mulroney. It is a pleasure to acknowledge their efforts. Special thanks goes to Meghan Cronin and Harris Kontoyiannis who helped in the data processing. Skip Carter supplied the basic objective mapping and contouring programs. The FESTSA time series analysis package was modified for use on the PRIME 750 by David Lai, Eva Griffith, and Mark Wimbush.

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Watts, D. R. and M. Wimbush. 1981. Sea surface height and thermocline depth variations measured from the sea floor. *International Symposium on Acoustic Remote Sensing of the Atmosphere and Oceans, Proceedings*, Calgary, Alberta, Canada.

## REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION unclassified		1b. RESTRICTIVE MARKINGS -----	
2a. SECURITY CLASSIFICATION AUTHORITY -----		3. DISTRIBUTION/AVAILABILITY OF REPORT	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE -----			
4. PERFORMING ORGANIZATION REPORT NUMBER(S) University of Rhode Island, Graduate School of Oceanography Technical Report 88-1		5. MONITORING ORGANIZATION REPORT NUMBER(S) -----	
6a. NAME OF PERFORMING ORGANIZATION University of Rhode Island Graduate School of Oceanography	6b. OFFICE SYMBOL (If applicable) ---	7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code)  South Ferry Road Narragansett, R.I. 02882		7b. ADDRESS (City, State, and ZIP Code)	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Office of Naval Research	8b. OFFICE SYMBOL (If applicable) Code 422 P.O.	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-86-C-0394	
8c. ADDRESS (City, State, and ZIP Code)  Code 422 P.O., 800 North Quincy Arlington, VA 22217		10. SOURCE OF FUNDING NUMBERS	
11. TITLE (Include Security Classification) The Synop Pilot Experiment: Inverted Echo Sounder Data Report for November 1986 to March 1987			
12. PERSONAL AUTHOR(S) Hy'in Sook Kim, Karen L. Tracey and D. Randolph Watts			
13a. TYPE OF REPORT Summary	13b. TIME COVERED FROM Nov '86 to Mar '87	14. DATE OF REPORT (Year, Month, Day) 1988 Nov 30	15. PAGE COUNT 63
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) path characteristics, time-varying current structure, transport of the Gulf Stream, Inverted Echo Sounder,	
19. ABSTRACT (Continue on reverse if necessary and identify by block number)  The SYNOP Pilot Experiment was conducted off Cape Hatteras, from late November 1986 to early March 1987, to measure the path characteristics (position, angle, curvature), the time-varying current structure and transport of the Gulf Stream. Part of the purpose of this Experiment was to test new instrumentation techniques and moored array designs for a subsequent main SYNOP Experiment. Data collected as part of the Pilot Experiment included Inverted Echo Sounders (IESs), Current Meters (CMs), and Acoustic Transport Meters (ATMs). This report documents the IES data and ATM data collected during the deployment period. Time series plots of the travel time and low-pass filtered thermocline depth measurements are presented for eleven instruments. Bottom pressure and temperature, measured at three of the sites, are also plotted. Basic statistics are given for all the data records shown. Maps of the thermocline depth field in a 160 Km by 140 Km region are presented at daily intervals.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL		22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL

Current Meters, Acoustic Transport Meters